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AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

547.
(Vol. XXVII.—September, 1892.)

RAINFALL, FLOW OF STREAMS, AND STORAGE.

By DESMOND FITZGERALD, M. Am. Soc. C. E.

READ JUNE 8TH, 1892.

WITH DISCUSSION.

The accompanying tables were prepared during the summer of 1891, for the purpose of calculating the yield of drainage areas with varying proportions of land and water surface. The results contained in this paper are intended for use in Massachusetts. They may, perhaps, be found applicable to a very much larger area.

Rainfall.—There is hardly any phenomenon about which so many misstatements are commonly made as that of rainfall. Either, "the cutting down of the forests is fast diminishing the annual precipitation" or else the latter is "increasing rapidly from turning up of the ground," and other causes. "There are no longer such snow storms as we used to have." "The rains come now altogether in the spring." "'Freshets' and 'droughts' alike come from great changes in the rainfall." These and a multitude of other fallacies are constantly met with. As a matter of fact, the annual rainfall is such a varying quantity that it is

extremely difficult to lay down general laws in regard to certain of its phases, even with the aid of a good rainfall table.

Again, the observations themselves are frequently inaccurate, as can sometimes be told at a glance. The earlier results were generally too small, because the gauges were placed too high and less care was exercised to measure all the small showers and the snow. Too often the tables issued from official sources and stamped with the approval of the Government are open to this criticism.* The periods also are generally too short to build safe theories upon; and, lastly, self-interest connected with important commercial enterprises leads to false statements.

Table No. 1 contains a compilation of seventy-four years of rainfall, by months, in the vicinity of Boston, and is now first made public. Another table, not here published, contains a record of rainfall observations 1852–91, made at Lake Cochituate, about 15 miles from Boston, and Table No. 2 gives the rainfall on the Sudbury River water-shed from 1875–90 inclusive.

Yearly Means.—The yearly means from these tables are as follows:

Boston, seventy-four years..................	47.00 inches.
Cochituate, forty years.....................	47.98 "
Sudbury, sixteen years.....................	45.80 "

An examination of the yearly fluctuations from these means, taken in connection with the methods of making the observations, does not disclose any definite law of increase or decrease. If there is a secular change, it is probably too slight to be observed in a century, especially where the observations are not all taken under exactly the same conditions and those conditions such as experience has shown to be necessary. The Providence and Lowell records make the average for the year about 45 inches.

As there is a liability to underestimate rather than to overestimate the rainfall,† the writer assumes that a general average for Boston cannot be far from 48 inches, or 4 inches per month.

Maximum and Minimum Rainfall.—The largest annual rainfall recorded in Table No. 1 occurred in 1863, 67.72 inches, and the smallest in 1822, 27.20 inches. If these figures are correct, they show how great

* The Signal Service observations of rainfall made on the tops of high buildings are untrustworthy.

† Largely from placing the gauge too high above the surface of the ground.

the range is. They cannot be far from the truth, because in 1883 the record of 32.78 inches on the Sudbury is corroborated by the record of many gauges, and the rainfall tables of Lowell, Providence, Waltham and other places all point to a minimum of about 30 inches. The writer has ascertained by an examination of the original records that the rainfall recorded at Waltham, of 26.9 inches, in 1846, included ten months only, and that the record at Lowell of 28.46 inches in 1825 contained nine months only. Such facts as these are sufficient to make us exceedingly cautious in regard to records. In a general way it is safe to say that the yearly rainfall varies from 30 to 60 inches. The minimum monthly rainfall was 0.23 inches in September, 1884, and the maximum properly recorded in any one month is probably not far from 12 inches.

Monthly Means.—The following table shows the monthly means:

	Boston, 1818–91.	Cochituate. 1852–91.	Sudbury, 1875–90.
January	3.98	3.88	4.18
February	3.78	3.62	4.06
March	4.36	4.25	4.58
April	4.06	3.97	3.32
May	3.79	3.87	3.20
June	3.27	3.31	2.99
July	3.71	4.23	3.78
August	4.39	4.94	4.23
September	3.55	3.59	3.23
October	3.84	4.29	4.41
November	4.31	4.44	4.11
December	3.96	3.59	3.71
	47.00	47.98	45.80

The progress of the monthly fluctuations can be seen in the diagram on the following page (Fig. 1).

There is a strong similarity in the profiles, too decided to be the subject of chance. The Providence rainfall (1832–91) has been added in a series of small circles.* They correspond to the general form of the other lines.

Whatever doubt we may have in regard to individual observations, the general accuracy of the average monthly distribution must be conceded. Longer observations may change the maximum and minimum points, but the present weight of evidence seems to favor March, August and November for maxima, and June and September for minima.

* The Providence rain gauge previous to 1876 was 7 feet above the ground, and must have given too small a result.

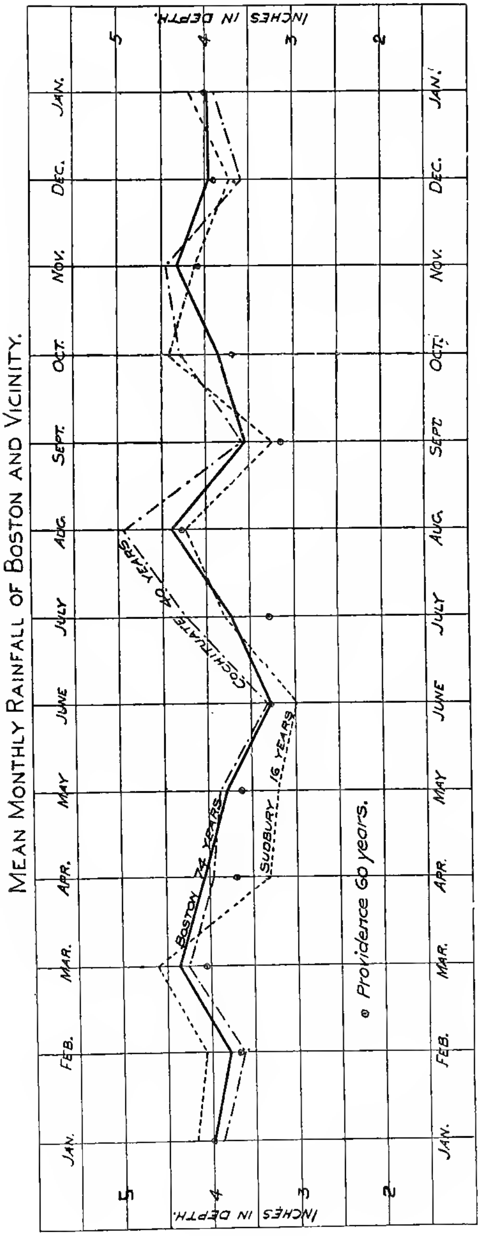
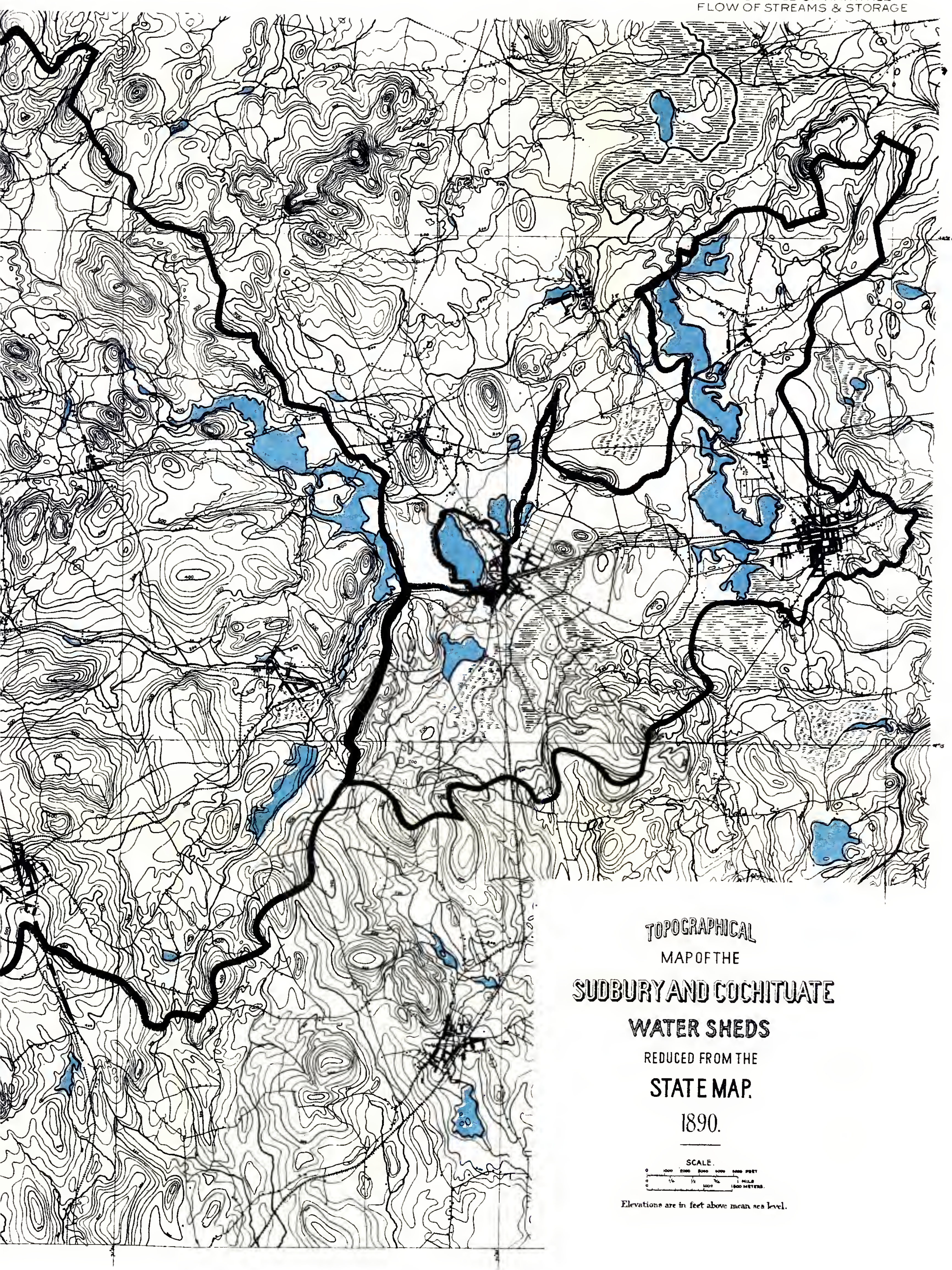

Mean Monthly Rainfall of Boston and Vicinity.
Inches in depth.
5
4
3
2
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Boston 74 years.
Cochituate 40 years.
Sudbury 16 years.
Providence 60 years.

Fig. 1.


TOPOGRAPHICAL
MAP OF THE
SUDBURY AND COCHITUATE
WATER SHEDS
REDUCED FROM THE
STATE MAP.
1890.
SCALE.
Elevations are in feet above mean sea level.

Seasonal Distribution.—The seasonal distribution is as follows:

	Boston.	Cochituate.	Sudbury.
Spring	12.21	12.09	11.10
Summer	11.37	12.49	11.00
Autumn	11.70	12.31	11.75
Winter	11.72	11.09	11.95

From these figures it is obvious that the rainfall is evenly distributed through the seasons of the year.

Evaporation.—The total flow of a stream must equal the rainfall, less the evaporation and other losses. As the latter are generally insignificant, the difference between the rainfall and the rainfall collected, is the total evaporation from the water-shed supplying the stream. The average of a number of years shows us that from 45 to 50 per cent. of the rainfall flows away in the stream; and if the average rainfall is 48 inches, then about 24 inches are evaporated yearly from the ground and other surfaces ordinarily found on a water-shed. The evaporation from a water surface is greater than that from the ground. Table No. 5 is an attempt to represent the monthly evaporation from a water surface during the period embraced in the other tables. The data upon which the table is founded are taken from a paper on "Evaporation," published in the *Transactions* of this Society in 1886 (Vol. XV, p. 581), but some observations made since the paper was published have been added. It appears from the table that the mean evaporation from a water surface in Boston is 39.2 inches, or about 82 per cent. of the mean rainfall, although it must be remembered that there is no connection between rainfall and evaporation. The diagram on page 258 (Fig. 2) is a new diagram of mean evaporation, which contains additional data on that already published.

Description of Water-Sheds.—The topographical map (Plate XLV) accompanying this paper gives an idea of the nature of the Sudbury and Cochituate water-sheds, but a few words of description seem necessary.

The Sudbury River water-shed has an area of 75.199 square miles; the Mystic, 26.9 square miles; and the Cochituate, 18.87 square miles. They together form the sources of Boston's water supply. The Sudbury is hilly, with steep slopes. There are, however, some large swamps within its borders. The Cochituate, although adjoining

the Sudbury, is entirely dissimilar. The slopes are flat and sandy. Its surface is mostly modified drift, while the Sudbury is largely composed of unmodified drift. The Mystic water-shed lies to the north of Boston, and about 30 miles distant from the other two sources which are to the west of the city. Its surface is steeper than the Cochituate, and not as steep as the Sudbury.

MEAN MONTHLY EVAPORATION CURVE.

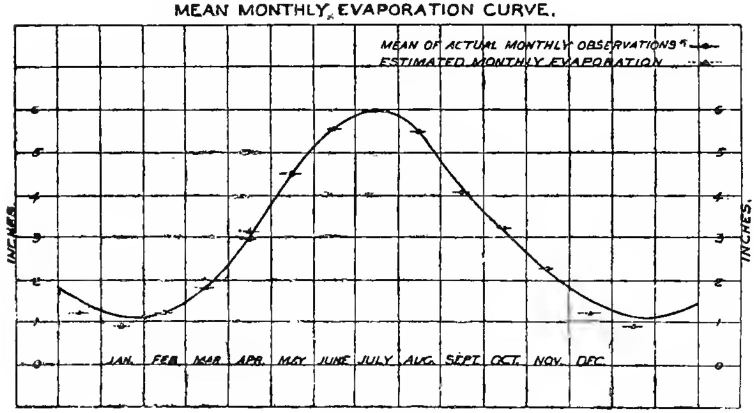


FIG. 2.

Flow of Streams.—However uniformly the rainfall is distributed, on the average, throughout the year, the effect of the excessive evaporation during the summer and of the frozen ground with accumulations of snow from month to month in the winter, is to produce a most irregular flow in the streams. During seven months of the year, from November to May inclusive, the streams have a large flow, and during five months, from June to October, a small flow ; but it is in February, March and April that we must look for the very large yields.

Table No. 15 contains the yields of the three water-sheds for various periods and combined in several ways. The results are different in some particulars, but in general agree sufficiently well to form the basis for an instructive investigation. The widest variation that is found in the tables, exists between the Sudbury and Cochituate collections. On the average, the latter collects 12 per cent. less water than the Sudbury. It is probably true that the Sudbury water-shed gives a somewhat larger yield than the average water-shed. It collects much more in the spring than the other two water-sheds, and rather less in the summer. It is impossible in the limits of this paper to go into an

extended discussion of the causes leading to these differences in collection, but the writer has thought that a better average, or typical collection, would be obtained by uniting the results of all three.

Monthly Yield.—In the diagram on page 260 (Fig. 3) the average monthly yields of the three water-sheds have been plotted for the period 1878–90, inclusive. The heavy line is a mean of the three, and for convenience the values are here repeated with their equivalents in cubic feet per second.

YIELD OF A TYPICAL NEW ENGLAND WATER-SHED PER SQUARE MILE.

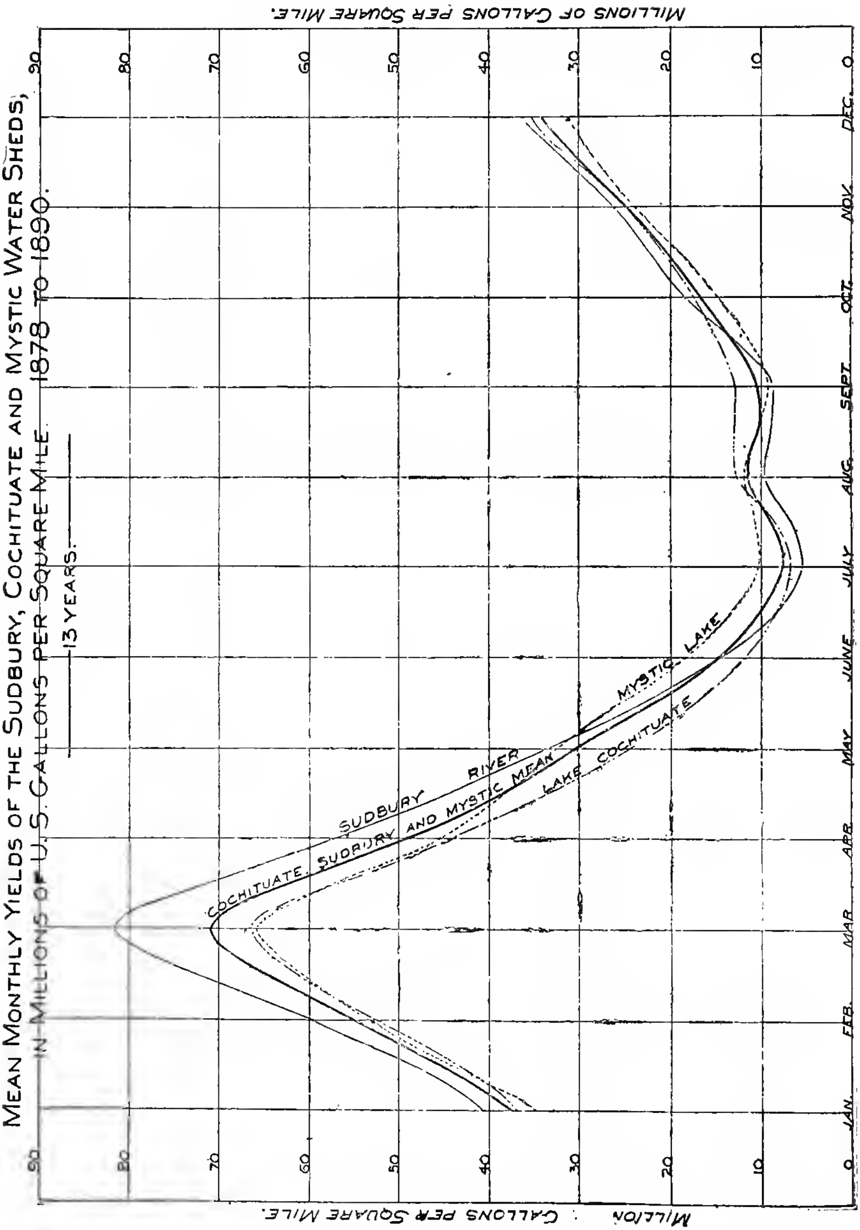
	GALLONS.	CUBIC FEET PER SECOND.
January	37 387 000	1.866
February	56 066 000	3.042
March	71 226 000	3.655
April	49 107 000	2.533
May	30 406 000	1.618
June	14 975 000	0.772
July	7 491 000	0.374
August	11 399 000	0.569
September	10 242 000	0.528
October	16 797 000	0.838
November	24 787 000	1.278
December	34 128 000	1.703
Total and Mean	363 001 000	1.539

It will be convenient for many purposes, especially where questions connected with the use of water for purposes of power are concerned, to use these monthly results in the order of their magnitude as follows:

AVERAGE MONTHLY YIELD PER SQUARE MILE IN ORDER OF MAGNITUDE.

	Cubic Feet per Second.
July	0.374
September	0.528
August	0.569
June	0.772
October	0.838
November	1.278
May	1.518
December	1.703
January	1.866
April	2.533
February	3.042
March	3.555
Mean	1.539

Fig. 4 contains the above quantities in graphical form.



Mean Monthly Yields of the Sudbury, Cochituate and Mystic Water Sheds, 1878 to 1890.
in Millions of U.S. Gallons per Square Mile
13 Years.
Millions of Gallons per Square Mile.
90
80
70
60
50
40
30
20
10
0
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Sudbury River
Cochituate, Sudbury and Mystic Mean
Mystic Lake
Lake Cochituate

Fig. 3.

The average yield of the Sudbury River water-shed alone for sixteen years is 1.669 cubic feet per second, which corresponds very closely to the Croton water-shed mean of 1.626.

The month of May represents the mean monthly flow for the entire year.

Ordinary Flow of a Stream.—The ordinary flow of a stream certainly does not mean the average flow, for one or two heavy freshets occurring in a few days in the spring of the year have a great influence on the

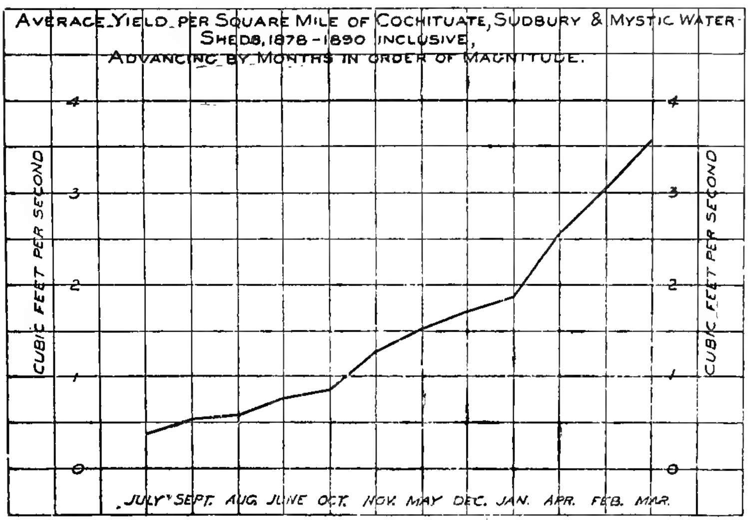


FIG. 4.

average without affecting in any way the ordinary run of water. The large flows above the average, occurring at the summit of the diagram (Fig. 4), in the months of February, March and April, should evidently be excluded. The flow in July is too insignificant to be considered. If we take the months above the average, at the average rate, and add to these the months below the average, excluding the month at the bottom of the list, and divide by the whole year, we shall, in the opinion of the writer, get a fair ordinary flow of the stream.

Applying this rule to the results already obtained we have :

	Gallons.
September.........	10 242 000
August............	11 399 000
June..............	14 975 000
October...........	16 797 000
November.........	24 787 000
May...............	30 406 000
Five months of mean flow,	149 178 000
	257 784 000

257 784 000 ÷ 365 = 706 000 gallons per day, or about 1.1 cubic feet per second per square mile.

Maximum Yield.—On the average, March is the month of maximum yield and its flow is about two and one-third times the mean monthly flow and about one-fifth the entire flow for the year. In March, 1877, the Sudbury water-shed (Table No. 8) yielded 149 222 000 gallons per square mile, or 7.448 cubic feet per second per square mile; about one hundred times the minimum monthly yield. This flow averaged 4 807 000 gallons daily per square mile for thirty-one days. It is the largest flow recorded for a month in the sixteen years.

Freshets.—The greatest freshet occurring on the Sudbury water-shed took place February 10th–13th, 1886, and a full description of its effects can be found in the *Transactions* of the Society for September, 1891. The maximum yield for twenty-four hours was equal to 1.54 inches in depth upon the surface, or 26 763 260 gallons per square mile, or 41.4 cubic feet per second per square mile; and the maximum rate of yield was equal to 1.646 in depth on the water-shed in twenty-four hours, or 44.2 cubic feet per second per square mile. On March 26th, 1876, a freshet giving nearly the same yield occurred, so that it is not probable that this amount of rainfall collected in twenty-four hours is very unusual.

Gaugings on a small affluent of the Sudbury, embracing 6.434 square miles of surface, showed a similar flow per square mile to that in the main stream. The maximum rate for twenty-four hours in the small affluent was equal to 1.801 inches of depth on its drainage area. Although these freshets were considered very disastrous in Massachusetts, they cannot be considered large when compared with what has been observed in neighboring water-sheds. Freshets of 3 and 4 inches

collected in twenty-four hours are within the experience of many hydraulic engineers, and it certainly would not be safe in designing dams to provide for less than 6 inches collected in twenty-four hours and flowing continuously, or 104 272 440 gallons per square mile per twenty-four hours, or 161.3 cubic feet per second. These remarks are of course applicable only to an ordinary New England water-shed not covered with houses and streets. The water-works engineer who is constantly designing waste weirs, dams, reservoirs, etc., may find it convenient to bear in mind that one square mile of land surface yields approximately 1.5 cubic feet per second throughout the year and that the maximum freshet flow may be one hundred times this amount or 150 cubic feet per second. In millions of gallons these become one million and one hundred millions respectively.

Minimum Yield.—The minimum daily yield of a stream is a dangerous subject for figures. There are so many conditions tending to affect the daily flow, even on the average water-shed, that it may often be something that man controls by his use of mill dams, storage basins, etc. Taking a period of a month, the Sudbury has shown in September, 1884 (Table No. 8), a yield as small as 1 318 000 gallons per square mile, or 43 930 gallons daily per square mile, equivalent to 0.068 cubic feet per second per square mile. The water surface during this month was 0.0303 of the total area.

Clemens Herschel, M. Am. Soc. C. E., reported to this Society in July, 1881,* that the Connecticut River, with 3 287 square miles of drainage area, had discharged as low as 0.306 of a cubic foot per second per square mile. Other large rivers in the country have shown a lower yield than this.

The discharge of a small water-shed, say, 2 or 3 square miles in area, in a protracted drought may be practically nothing. The geological formations on a water-shed have an important bearing on the minimum yield. If there are large plains of loose gravel or sand which hold water, and whose water tables are drawn down in the summer, the minimum flow is larger than where the same areas are occupied by unmodified drift.

Average Daily Yield.—It is apparent from an inspection of the tables that the average daily yield per square mile of an average water-shed is about 1 000 000 gallons, or 1.5472 cubic feet per second.

* Vol. X, *Transactions*, page 238.

Percentages of Rainfall Collected.—Percentages are almost as dangerous to deal with as the minimum flow. In many ways percentages are instructive. They bring home forcibly to the mind the relation existing between the rainfall and the flow in the streams at different seasons of the year, but their results must be interpreted with a knowledge of the prevailing conditions.

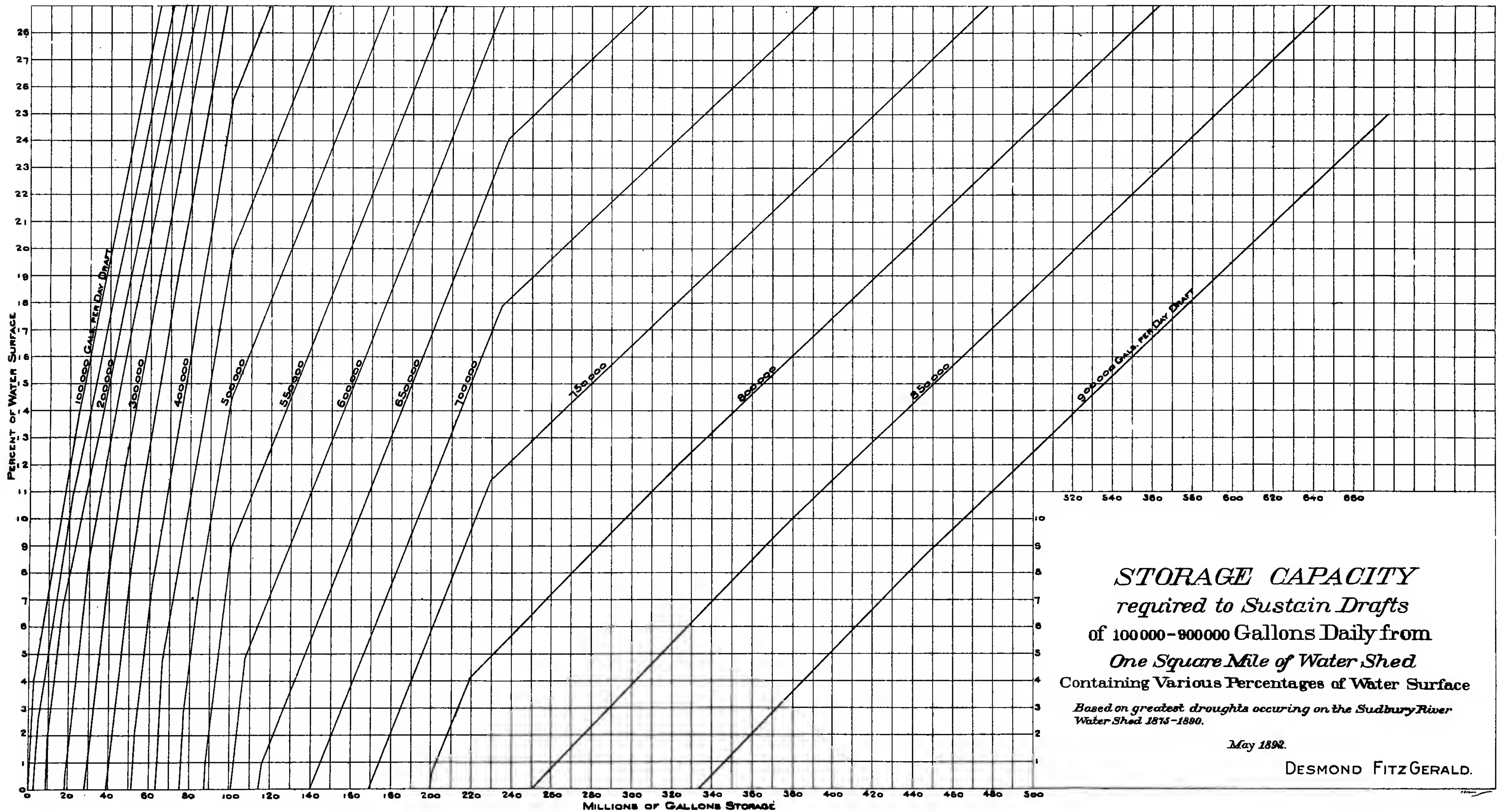
Table No. 4 contains the monthly percentages of rainfall collected on the Sudbury for sixteen years. To the general monthly averages of this table, the monthly averages in the Cochituate water-shed from 1863–91, inclusive, have been added in the following table for purposes of comparison.

MEAN PERCENTAGES OF RAINFALL COLLECTED.

	Sudbury, 1875–90.	Cochituate, 1863–91.
	Per Cent.	Per Cent.
January	49.1	53.1
February	78.2	71.9
March	109.6	84.6
April	109.1	83.8
May	62.3	47.9
June	29.1	27.9
July	8.9	13.1
August	13.0	17.7
September	14.2	23.6
October	23.1	23.6
November	39.5	34.0
December	62.5	49.9
Mean	49.6	43.8

The percentages exceeding 100 are caused by accumulations of rainfall, generally in the form of snow, from one month to another, passing off finally in a different month from that in which it fell. In considering monthly collections, it must not be forgotten that the amount of rain falling in the previous month has a large influence on the collections of the month following, especially in porous water-sheds. A knowledge of this fact will often explain what seem to be anomalous results.

The yearly percentages of rainfall collected on the Sudbury have varied from 31.9 per cent. in 1880 to 62.2 in 1888, and on the Cochituate from 25.7 per cent. in 1866 to 69.1 per cent. in 1891. The mean for sixteen years on the Sudbury is 49.5 per cent., and for twenty-nine years on the Cochituate 43.8 per cent. The percentages depend upon the



STORAGE CAPACITY
required to Sustain Drafts
of 100000-900000 Gallons Daily from
One Square Mile of Water Shed
Containing Various Percentages of Water Surface

Based on greatest droughts occuring on the Sudbury River Water Shed 1875-1890.

May 1892.

DESMOND FITZGERALD.

distribution of the rainfall throughout the year. A heavy summer rainfall and a light winter rainfall mean a small percentage of collection, and, conversely, a light summer and a heavy winter rainfall mean a large percentage of collection, so that the total rainfall for the year is but a partial index to the yield of a water-shed.

If, on the average, 11 per cent. only of the rainfall in July is collected, it becomes evident that the amount of the rainfall in that month, speaking within ordinary limits, is of but little consequence for most purposes connected with water supply; and, still further, it may be said that for systems which depend upon storage, it is not the summer droughts which are to be dreaded, but the winter and spring droughts; for it is the flow in these months upon which we depend to fill the reservoirs. In July, 1876, the percentage of rainfall on the Sudbury fell to 3.6.

Storage.—Owing to the great variations in flow, as already shown, the question of storage becomes of great importance in schemes which look to developments of available supplies from water-sheds. In a report made by the writer in 1887 on "The Available Capacity of the Sudbury River and Lake Cochituate Water-Shed in Time of Drought," a method of showing graphically the storage required in the periods of deficiency from 1875 to 1887 was given, in the form of a mass curve after Rippl.*

This curve is found by plotting the differences between the yields and the daily drafts. By this method the storage required for the given daily draft in the periods of deficiency is easily found.

By means of Tables Nos. 11 and 13 (pages 281 and 283), which give the yield of the Sudbury water-shed for sixteen years, by months, reduced to 1 square mile of land surface and 1 square mile of water surface, it will be possible to find the yield of any water-shed, whatever its ratios of land and water surface.

Having found the yield, it will then be an easy matter to ascertain the extent of the periods of deficiency for any given draft, or the periods when the yield is less than the draft. To save the trouble of these computations, the table (page 267) has been prepared, showing at once the maximum storage required to tide over the droughts between 1875–90, and for different daily drafts from 100 000 to 900 000 gallons, and ap-

* W. Rippl. "The Capacity of Storage Reservoirs for Water Supply." Min. Proc. Inst. C. E., Vol. 71, p. 270.

plicable to different percentages of water surfaces found upon the given water-shed. The table is reduced to the unit of one square mile, so that a simple multiplication will give the required storage upon any given number of square miles.

As the greatest period of deficiency or the most prolonged and severest drought is the one on which this table is based, and must ever be the one to which the cautious engineer turns for instruction, it may be interesting to remember that this period from 1875 to 1890, inclusive, contains two years of most remarkable drought, following each other closely. These were the years 1880 and 1883; in fact, the period of yield from 1879 to 1884 forms a crucial test or measure of what may be expected in the future. The value of exact measurements during this period will be the better appreciated when we take into consideration that the rainfall records for sixty years, 1830-90, give no evidence of any more severe period of drought.

Of the future certainly we know nothing; but, judging by the past, we may feel assured that we have done all that a reasonable care demands, if our works are proportioned to the maximum drought occurring in so long a period as sixty years.

The following is an example of the use of the table. Suppose we have a water-shed of 40 square miles which contains 10 per cent. of water surface, and we wish to draw daily 500 000 gallons. The question is how much storage must be provided. Look in the left hand column for 500 000, and follow this line to the column headed 10 per cent.; here, we find the figures 90 550 000 gallons storage per square mile, which, multiplied by 40, gives 3 622 000 000 gallons—the required storage.

The diagram Plate XLVI, which is a plot of the table under discussion, will facilitate the taking out of quantities for intermediate percentages not given in the table. The horizontal lines are the ratios of water surface. The perpendiculars dropped from the intersections of these horizontal lines with the various lines of draft will give, at the bottom of the diagram, the required storage in millions of gallons.

When storage reservoirs are distributed on different portions of a water-shed, it is important to consider them with reference to their positions, the extent of their individual drainage areas, and their capacities for yield in connection with the other portions of the water-shed; and these studies afford some of the most interesting problems for the water-works expert. It is believed that the data collected in this paper will give the means for solving these problems.

TABLE SHOWING STORAGE CAPACITY REQUIRED TO SUSTAIN A CONSTANT DAILY DRAFT FROM ONE SQUARE MILE CONTAINING VARIOUS PERCENTAGES OF WATER SURFACE.

Based on Sudbury River Water-Shed.—Sixteen Years.—U. S. Gallons.

Constant Daily Draft.	0 per cent.	2 per cent.	4 per cent.	6 per cent.	8 per cent.	10 per cent.	15 per cent.	20 per cent.	25 per cent.
100 000	314 000	1 289 000	2 666 000	6 973 000	10 992 000	15 012 000	26 883 000	40 224 000	53 565 000
150 000	3 006 000	4 711 000	7 652 000	11 673 000	15 692 000	19 642 000	32 983 000	46 324 000	59 665 000
200 000	8 797 000	9 937 000	12 802 000	15 666 000	20 427 000	25 742 000	39 083 000	52 424 000	65 765 000
250 000	17 997 000	20 637 000	23 502 000	26 366 000	29 230 000	33 338 000	45 449 000	58 524 000	71 865 000
300 000	28 473 000	31 337 000	34 202 000	37 066 000	39 930 000	43 437 000	54 599 000	66 702 000	78 807 000
350 000	39 173 000	42 037 000	44 902 000	47 766 000	50 630 000	54 137 000	64 812 000	75 852 000	87 957 000
400 000	51 303 000	52 788 000	55 602 000	58 466 000	61 643 000	66 050 000	77 062 000	88 076 000	99 089 000
450 000	63 553 000	65 038 000	66 526 000	69 458 000	73 893 000	78 300 000	89 312 000	100 970 000	127 412 000
500 000	75 803 000	77 288 000	79 106 000	82 131 000	86 143 000	90 550 000	103 474 000	129 920 000	156 362 000
550 000	88 053 000	89 877 000	92 905 000	95 031 000	98 958 000	105 987 000	132 424 000	158 870 000	185 312 000
600 000	100 651 000	103 677 000	106 705 000	113 781 000	124 357 000	134 937 000	161 374 000	187 820 000	214 262 000
650 000	114 451 000	121 577 000	132 154 000	142 731 000	153 307 000	163 887 000	190 324 000	216 770 000	250 744 000
700 000	139 950 000	150 627 000	161 104 000	171 681 000	182 257 000	192 837 000	219 274 000	265 546 000	338 044 000
750 000	168 900 000	179 477 000	190 054 000	200 631 000	211 207 000	221 787 000	280 343 000	350 846 000	421 344 000
800 000	199 106 000	208 427 000	219 004 000	244 446 000	270 452 000	297 460 000	365 613 000	436 146 000	506 644 000
850 000	250 328 000	276 275 000	302 240 000	328 195 000	354 202 000	380 557 000	450 943 000	521 446 000	591 944 000
900 000	334 078 000	360 025 000	385 990 000	411 945 000	437 952 000	465 857 000	536 243 000	606 746 000	677 244 000

In a valuable report by Mr. Frederic P. Stearns, M. Am. Soc. C. E., to the Massachusetts State Board of Health, on "The Selection of Sources of Water Supply," the author has given a series of diagrams illustrating the fluctuations of a reservoir caused by different daily drafts. These diagrams show that, no matter what the extent of the storage may be, the effect of drafts beyond, say, 600 000 gallons daily per square mile, is to keep a storage reservoir below high water for several years.

The importance of this warning cannot be too strongly impressed upon the engineer who is designing systems of storage. The following table, calculated for 0, 10 and 25 per cent. water surfaces, shows the length of time that a reservoir would be below high water during the sixteen years we are considering, and under various drafts.

PERIODS DURING WHICH ANY RESERVOIR WILL BE BELOW HIGH WATER.

Daily draft per square mile.	Percentage of Water on Water-Shed.		
	0 per cent. Covered Reservoir.	10 per cent.	25 per cent.
100 000 gals.........	1½ months.	6½ months.	7½ months.
150 000 "	3½ "	7½ "	8½ "
200 000 "	7½ "	7½ "	8½ "
250 000 "	7½ "	8½ "	8½ "
300 000 "	8½ "	8½ "	8½ "
350 000 "	9½ "	9½ "	9½ "
400 000 "	9½ "	10½ "	10½ "
450 000 "	9½ "	10½ "	1 year, 9½ "
500 000 "	9½ "	10½ "	1 " 9½ "
550 000 "	9½ "	1 year, 9½ "	1 " 10½ "
600 000 "	10½ "	1 " 9½ "	1 " 10½ "
650 000 "	10½ "	1 " 9½ "	7 " 8½ "
700 000 "	1 year, 9½ "	1 " 10½ "	8 " 10½ "
750 000 "	1 " 9¼ "	1 " 11½ "	9 " 7½ "
800 000 "	4 " 10½ "	7 " 8½ "	10 " 5½ "
850 000 "	6 " 8½ "	8 " 11½ "	11 " 9½ "
900 000 "	7 " 9½ "	9 " 8½ "	Probably about 13 yrs., 9 mos.

As it is undesirable to keep the water below high water for more than two years in succession, it will be seen that, no matter what the extent of the storage may be, it is impracticable to secure more than about 750 000 gallons daily from 1 square mile of water-shed containing 10 per cent. of water surface. As there are circumstances which permit of a different method of managing a storage basin and, where the bad influences of keeping the water low for several years are immaterial, the table for storage is carried to 900 000 gallons daily draft. With this draft a basin on the Sudbury River water-shed would have been one hundred and six and a half months or nearly nine

years, without filling to its high water-line during the period 1875–90, and a heavy growth of vegetation would undoubtedly have sprung up on the exposed margins during this long interval.

To secure this draft a storage of 377 800 000 gallons per square mile becomes necessary, which, if provided, would change the percentage of water surface from 3½ to 12 per cent., reckoning depths usually found, and requiring an increase of another hundred millions of gallons to the storage, which in turn requires another correction for increase of water surface.

The writer has had an opportunity to apply the calculated yields from various percentages of land and water surface to three water-sheds—one with no water surface, another with 5 per cent. of water surface, and the third with 25 per cent. of water surface. Daily gaugings of flow were made for sixteen months, with the results shown in the following table:

THREE WATER-SHEDS WITH VARYING PERCENTAGES OF WATER SURFACE.
Ratios of Calculated Yields to Weir Measurements.

	0 Per Cent.	5 Per Cent.	25 Per Cent.
1890.—February	0.957	0.934	0.958
March	0.925	1.031	1.005
April	1.056	0.965	0.864
May	0.945	0.865	0.859
June	1.297	1.029	0.634
July	13.391	0.713	1.742
August	4 320	0.548	−0.277
September	1.041	0.885	1.045
October	0 850	1.110	1.164
November	1.201	1.343	0.982
December	0.950	0.909	0.908
1891.—January	1.034	0.983	1 010
February	1.070	1.009	0.996
March	1.012	1.141	1.028
April	1.060	1.095	1.018
May	1.024	0.821	0.578
	1.014	1.023	0.977

With the exception of the 0 per cent., these ratios are thought to be satisfactory as showing the general accuracy of the data on which the yields for different percentages of water surface are based. A large swamp upon the water-shed, with no water surface, probably caused the failure in the case of the 0 per cent., which, however, is somewhat magnified in the table by the fact that the yield was small, though the ratios are large. The writer is inclined to caution engineers against the use of the table for 0 per cent. of water surface on account of the difficulty of finding areas of any great extent free from ponds, swamps or marshes. It is doubtful if it is advisable to use anything under 2 per cent.

TABLE No. 1.

Boston Rainfall—74 Years.

1818–23. Dr. Enoch Hale. Carefully collated from original records. Snow melted and measured.

1823–66. Jonathan P. Hall. From 1823 to 1856 taken from Am. Acad. Arts and Sciences Memoirs Vol. VI, n. s., pp. 229, 308.*

1866–85. Supt. of Sewers.† 1885–1891. Boston Water-Works.

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	For the Year.
1818..	2.64	3.49	4.05	6.15	5.95	3.47	4.08	0.46	7.81	2.11	1.91	0.86	42.99
1819..	0.70	2.27	6.21	3.74	3.06	3.56	2.02	4.38	5.29	1.40	1.22	1.63	35.48
1820..	3.12	4.25	4.90	0.45	5.08	3.42	4.19	5.15	2.43	5.39	3.00	2.80	44.18
1821..	1.41	4.42	2.53	4.90	4.84	2.79	2.35	1.58	4.73	2.29	3.12	1.93	36.89
1822..	1.29	2.34	2.02	2.99	0.78	3.54	4.32	1.20	2.15	2.53	2.58	1.46	27.20
1823..	3.00	4.57	7.72	2.21	6.40	0.93	5.74	1.98	1.95	3.95	1.92	6.93	47.30
1824..	3.95	5.99	1.81	4.72	1.43	1.60	0.88	3.68	6.43	1.01	1.72	2.80	36.02
1825..	2.79	3.43	4.70	0.37	1.36	4.77	1.24	5.62	2.66	3.21	0.81	4.38	35.34
1826..	2.55	1.48	3.81	1.50	0.25	3.85	2.90	12.10	3 03	3.80	2.31	3.56	41.14
1827..	3.92	2.97	2.51	4.75	5.34	2.56	2.59	4.88	4.81	5.28	5.71	3.59	48.91
1828..	2.15	2.79	1.84	2.00	4.67	1.59	4.58	0.37	3.82	2.79	5.55	0.26	32.41
1829..	4.93	5.62	4.30	3.45	2.71	1.64	6.98	4.95	2·62	1.65	5.74	2.26	46.85
1830..	2.35	1.63	3.51	1.21	3.93	3.46	4.90	2.64	5.55	2.38	5.32	5.96	42.95
1831..	4.44	3.68	3.07	6.97	3.65	4.32	5.53	5.57	3.83	4.42	3.20	2.93	51.61
1832..	4.47	3 74	2.65	5.56	7.27	0.50	3.41	6.14	2.07	2.45	3.57	4.85	46.69
1833..	2.96	2.53	2.71	2.30	1.03	3.23	2.01	0.82	2.88	6.00	5.53	5.86	37.86
1834..	1.39	1.13	0.96	2.93	6.33	3.09	7.71	2 47	3.71	4.62	2.90	2.36	39.60
1835..	3.25	1.37	4.27	4.54	2.07	2.74	9.07	2.89	1.31	1.87	2.08	2.40	37.86
1836..	8.84	3.57	2.90	1.58	1.85	4.33	2.12	1.53	0.54	4.04	5.43	4.13	40.86
1837..	4.10	4.14	3.02	3.07	5.79	2.98	1.80	1.67	0 56	1.58	2.35	2.46	33.52
1838..	3.07	2.77	3.09	2.62	3.32	2.55	1.20	4.26	9.87	5.02	3.95	0.80	42.52
1839..	0.98	3.11	1.18	7.73	4.27	2.25	3.32	5.70	2.00	2.50	1.71	6.35	41.10
1840..	3.12	2.57	4.55	4.60	2.23	2.78	2.93	4.00	2.12	4.48	11.63	4.15	49.16
1841..	6.00	1.60	3.50	8.82	1.90	1 95	2.10	4.20	2.86	3.80	4.55	5.77	47.05
1842..	0.80	3.20	3.35	3.50	2.90	5.30	1.82	4.44	3.25	0.80	4.45	5.30	39.11
1843..	2.20	6.08	6.17	3.88	1.60	4.61	2.15	5.88	0.98	4.82	3.40	3.92	46.69
1844..	3.68	2.42	6.00	0.20	2.72	1.40	2.17	2.62	3.53	5.80	3.15	3.85	37.54
1845..	4.58	4.25	3.83	1.23	2.82	2.05	3.28	1.82	2.23	4.00	10.25	5.98	46.32
1846..	3.12	2.95	2.73	1.23	2.02	2.25	2.51	1.80	1.30	1.35	4.17	4.52	29.95
1847..	3.28	4.70	4.77	2.20	2.03	4.09	2.65	5.45	6.64	1.05	5.12	3.95	46.93
1848..	2.30	3.90	4.05	1.40	6.30	1.73	1.35	3.10	3.55	5.10	2.25	5.95	40.98
1849..	0.35	1.15	7.35	0.90	3.10	1.45	0.85	5.25	1.25	8.10	5.50	4.05	40.30
1850..	4.59	2.52	5.32	4.82	6.63	2.77	2.70	5.30	7.15	2.10	3.32	6.76	53.98
1851..	1·30	4.20	3.88	9.37	3 31	1.80	3.09	1.27	3.50	4.43	5.51	2.65	44.31
1852..	4.85	2.85	4.45	10.18	1.95	2.35	3.28	7.63	1.65	2.19	3.47	3.09	47.94
1853..	2.44	5.30	2.27	3.78	5.63	0.30	3.64	9.40	3.80	3.92	4.43	3.95	48.86
1854..	2.91	4.87	2.84	6.63	4.33	2.47	3.70	0.58	3.86	2.08	6.80	4.64	45.71
1855..	7.22	4.67	1.18	4.28	1.20	3.09	4 15	1.46	1.13	4.51	5.27	5.93	44.19
1856..	5.32	0.80	1.33	4.37	7.10	2.90	4.02	11.11	4.90	2.70	3.33	4.28	52.16
1857..	5.36	2.45	3.09	10.83	5.57	2.02	5.53	7.18	2.56	4.50	2.52	5.26	56.87
1858..	3.28	2.30	2.18	5.18	3.89	8.09	4.56	7.03	5.02	3.03	3.38	4.73	52.67
1859..	5.93	4.05	7.64	3.36	3.63	7.89	1.58	4.72	4.40	3.28	3.75	6 47	56.70
1860..	1.89	3.85	2.19	1.73	2.35	8.01	5.90	4.30	7.35	2.66	5.37	5.86	51.46
1861..	5.04	3.57	7.48	5.89	2.97	3.64	2.76	6.04	1.77	2.65	4.90	2.35	50.07
1862..	8.30	3.29	4.70	1.97	2.70	6.78	7.33	4.20	5.61	4.85	8.32	3.01	61.06
1863..	4.51	4.54	6.42	9.08	2.82	2.56	12.38	5.64	3.12	3.83	5.48	6.34	67.72
1864..	3.87	1.43	11.75	4.72	3.31	1.47	1.90	4.17	2.60	4.80	4.00	5.28	49.30
1865..	4.47	5.08	4.83	2.57	6.90	2.83	4.26	1.42	0.62	6.21	4.46	4.18	47.83
1866..	3.73	5.28	4.70	2.03	5.04	3.41	5.42	3.87	5.90	2.72	3.74	4.86	50.70
1857..	6.06	6.55	6.12	2'52	4.11	2.74	4.76	10.78	0.44	6.76	2.32	2.48	55.64
1868..	6.09	1.88	5.04	6.94	10.38	3.79	1.10	7.53	11.95	1.78	5.31	2.32	64.11
1869..	4.03	9.98	8.74	2.05	6.88	4.44	3.30	2.19	5.18	6.71	3.74	9.04	66.28
1870..	8.16	7.03	4.88	8.42	2.58	7.59	4.01	1.57	0.67	6.80	4.40	3.62	59.73
1871..	2.77	3.72	4.68	4.23	5.69	5.67	2.87	3.31	1.37	5.51	5.38	3.13	48.33
1872..	2.43	2.68	3.98	3.24	3.95	4.81	4.48	10.48	7.37	4.98	4.64	5.00	58.04
1873..	6.69	3.74	4.54	3.81	4.92	0.65	3.25	6.46	2.78	5.43	7.34	5.33	54.94

TABLE No. 1—*Continued.*

Year.	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	For the Year.
1874..	4.30	4.02	1.64	8.36	3.72	2.91	2.70	6.48	1.66	1.02	2.58	1.70	41.09
1875..	3.24	3.62	5.76	4.46	3.89	7.73	3.84	3.50	3.32	5.06	5.62	0.97	51.01
1878..	1.89	5.24	8.25	5.61	3.14	2.16	6.50	1.82	3.62	2.13	9.82	5.01	55.19
1877..	4.03	1.20	9.08	3.82	3.58	3.05	2.58	5.68	0.53	8.19	8.30	1.05	51.15
1878..	7.30	6.08	5.37	5.88	0.92	2.06	3.63	6.50	2.32	6.10	7.11	5.62	58.89
1879..	2.74	3.54	4.31	6.97	1.16	5.62	3.43	6.45	1.86	0.80	3.53	4.64	45.05
1880..	3.23	4.73	3.85	3.28	1.86	0.63	7.52	2.87	2.30	3.41	2.07	3.14	38.89
1881..	5.59	5·15	6.94	2.36	3.59	7.01	3.51	1.17	2.52	2.86	4.42	4.10	49.22
1882..	4.66	6.35	3.57	2.81	5.80	1.74	4.01	1.69	11.47	2.30	1.74	2.48	48.42
1883..	4.04	3.55	2.14	2.95	3.94	2.57	2.51	0.34	1.38	6.34	2.07	3.73	35.56
1884..	5.71	7.19	6.25	4.88	3.32	4.21	5.33	5.30	0.23	3.34	3.19	4.91	53.86
1885..	5.21	2.88	1.21	3.62	4.35	3.38	1.40	7.22	1.60	5.67	5.53	2.00	44.07
1888..	7.04	7.38	3.76	2.52	3.96	1.30	2.09	3.98	2.94	3.06	3.73	4.71	46.47
1887..	5.57	4.44	6.20	4.74	1.69	2.08	3.69	3.53	1.35	3.21	2.75	3.66	41.91
1888..	3.88	3.34	6.53	2.44	5.90	2.68	1.98	7.10	9.45	4.54	8.17	5.36	60.27
1889..	6.50	1.93	2.17	4.02	4.78	3.31	9.23	4.81	5.30	3.83	6.25	2.66	54.79
1890..	2.52	3.12	7.64	2.93	5.80	2.60	2.43	3.37	4.89	8.78	1.37	4.76	50.21
1891..	8.98	8.29	5.63	2.98	2.05	4.04	3.44	4.02	3.07	5.70	2.70	3.73	49.63
Totals	294.41	279.79	322.59	300.13	280.30	241.83	274.54	325.07	262.37	284.48	319.29	292.79	3477.66
Means	3.98	3.78	4.36	4.06	3.79	3.27	3.71	4.39	3.55	3.84	4.31	3.96	47.00

* Hall's gauge was 18 inches high, 12 inches diameter, and located 90 feet above tide-marsh. The snow was melted and measured.

† The Sewer and Water-Works gauges are 14.85 inches diameter, and the collections are weighed.

TABLE No. 2.

RAINFALL.—SUDBURY RIVER WATER-SHED—SIXTEEN YEARS.

NOTE.—Means of Observations at Several Places. Taken for 1875–86, from Special Report of May, 1887, on Capacity in Time of Drought, and for 1887–90, from Annual Reports of Water Board.

	1875.	1876.	1877.	1878.	1879	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90.	
																	TOTAL.	MEAN.
Jan.....	2.42	1.83	3.22	6.63	2.48	3.57	5.56	5.95	2.81	5.08	4.71	5.36	5.20	4.15	6.37	2.53	66.87	4.179
Feb	3.15	4.21	0.74	5.97	3.55	3.98	4.65	4.56	3.85	5.55	3.87	6.28	4.78	3.58	1.65	3.51	54.99	4.062
Mar....	3.74	7.43	8.35	4.59	5.14	3.31	5.73	2.55	1.78	4.72	1.07	3.61	4.90	5.02	2.37	7.73	73.25	4.578
Apr.....	3.23	4.20	3.44	5.79	4.72	3.10	2.00	1.82	1.84	4.40	3.60	2.23	4.26	2.43	3.41	2.66	53.12	3.320
May ...	3.55	2.76	3.70	0.96	1.58	1.84	3.51	5.06	4.19	3.47	3.49	2.99	1.17	4.82	2.94	5.21	51.25	3.203
June...	6.24	2.04	2.42	3.88	3.79	2.14	5.39	1.65	2.40	3.44	2.87	1.47	2.65	2.54	2.80	2.03	47.75	2.985
July....	3.57	9.13	2.95	2.97	3.93	5.27	2.35	1.77	2.68	3.67	1.43	3.26	3.76	1.41	8.94	2.46	60.55	3.784
Aug....	5.53	1.72	3.68	6.94	6.51	4.01	1.36	1.67	0.74	4.55	7.18	4.10	6.28	6.22	4.18	3.85	67.53	4.227
Sept ...	3.43	4.62	0.32	1.29	1.88	1.60	2.62	8.74	1.52	0.85	1.42	2.91	1.32	8.58	4.60	5.00	51.71	3.232
Oct	4.85	2.24	8.52	5.42	0.81	3.74	2.95	2.07	5.50	2.48	5.10	3.23	2.83	4.99	4.26	10.51	70.60	4.413
Nov	4.83	5.76	5.80	7.02	2.58	1.79	4.09	1.15	1.81	2.65	6.09	4.65	2.67	7.23	5.29	1.20	56.71	4.107
Dec.....	0.94	3.52	0.87	5.37	4.34	2.83	3.96	2.30	3.55	5.17	2.72	4.97	3.88	5.39	3.14	5.31	59.35	3.710
Total...	45.49	49.56	44.02	57.93	41.42	38.18	44.17	39.39	32.78	47.14	43.55	46.05	42.70	57.46	49.95	53.00	732.80	45.800

January, 1875, to December, 1876, Lake Cochituate, with April to December, 1876, Westborough and Hopkinton, and June to December, 1876, Southborough and Marlborough. December, 1876, to January, 1883, Framingham, Southborough, Marlborough, Westborough and Hopkinton. January, 1883, to January, 1884, Framingham and Southborough. January, 1884, to January, 1890, Framingham and Westborough. January, 1890, to January, 1891, Framingham and Ashland.

TABLE No. 3.

Yield of the Sudbury River Water-Shed in Inches of Depth—Sixteen Years—Inches Rainfall Collected.

	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90.	
																	Total.	Mean.
Jan	0.18	1.15	1.17	3.23	1.25	2.00	0.74	2.21	0.60	1.77	2.20	2.61	4.62	1.88	4.96	2.24	32.81	2.05
Feb ...	2.41	2.28	1.53	3.97	2.76	2.98	2.49	3.87	1.66	4.74	2.18	7.73	4.56	3.25	1.93	2.46	50.82	3.18
Mar....	2.86	7.91	8.59	6.26	4.16	2.46	7.14	5.06	2.87	6.75	2.80	3.67	5.12	5.78	2.39	6.50	80.31	5.02
Apr	5.26	5.68	4.13	2.81	5.38	2.02	2.67	1.50	2.33	4.92	3.13	3.36	4.62	4.57	2.43	3.24	57.96	3.62
May	2.12	2.03	2.48	2.49	1.99	0.92	1.72	2.30	1.67	1.84	2.38	1.28	1.80	2.91	1.67	2.44	31.94	2.00
June ...	1.50	0.38	1.03	0.87	0.71	0.30	2.31	0.91	0.52	0.72	0.73	0.35	0.71	0.73	1.13	0.98	13.90	0.87
July....	0.57	0.33	0.36	0.23	0.28	0.31	0.49	0.15	0.21	0.40	0.11	0.21	0.20	0.21	1.13	0.19	5.39	0.34
Aug....	0.71	0.72	0.22	0.85	0.70	0.21	0.26	0.10	0.14	0.46	0.43	0.17	0.38	0.68	2.65	0.23	8.82	0.55
Sept....	0.36	0.32	0.10	0.28	0.24	0.14	0.34	0.53	0.16	0.08	0.21	0.20	0.19	1.99	1.42	0.79	7.35	0.46
Oct.....	1.15	0.42	1.13	0.92	0.13	0.18	0.33	0.53	0.33	0.15	0.60	0.26	0.34	3.57	2.19	4.05	16.28	1.02
Nov	2.25	1.88	2.45	2.92	0.35	0.35	0.68	0.36	0.35	0.30	2.03	1.16	0.64	4.76	3.35	2.10	26.94	1.62
Dec	1.04	0.81	2.30	5.67	0.82	0.31	1.38	0.56	0.34	1.65	2.09	1.82	1.16	5.43	4.00	1.78	31.16	1.95
Total...	20.42	23.91	25.49	30.49	18.77	12.18	20.56	18.10	11.19	23.78	18.92	22.82	24.23	35.75	29.06	26.99	362.66	22.67

TABLE No. 4.

Percentage of Rainfall Collected—Sudbury River Water-Shed—Sixteen Years.

Note.—For the years 1875–79, and 1887–90, figures are copied from Reports of Boston Water Board.

	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90.	
																		Mean.
Jan	7.6	62.7	36.5	57.3	50.4	56.1	13.3	37.1	21.4	34.8	46.7	41.0	88.8	45.3	92.4	88.4	......	49.1
Feb....	76.5	54.2	206.9	66.5	77.4	74.9	53.6	85.1	42.9	72.4	56.4	123.1	95.3	88.3	116.4	70.3	......	78.2
Mar	76.5	106.6	102.7	133.4	80.9	74.0	124.6	191.0	161.2	143.0	261.7	101.7	104.4	95.9	100.9	84.0	......	109.6
Apr.....	162.9	135.4	120.3	48.5	114.1	65.1	133.6	82.2	126.3	111.7	86.8	151.0	106.0	188.3	71.4	122.3	......	109.1
May....	59.5	73.5	67.0	260.2	125.8	50.1	49.0	45.4	39.9	53.0	68.3	42.7	154.5	60.3	53.3	46.8	......	62.3
June...	24.0	18.8	42.5	22.5	18.8	14.0	42.8	54.7	21.7	20.9	25.5	23.9	26.9	28.7	40.3	48.3	......	29.1
July....	16.0	3.6	12.2	7.7	7.1	4.9	20.9	8.5	7.8	10.9	7.7	6.4	5.4	14.9	12.6	7.8	......	8.9
Aug....	12.8	42.0	5.9	12.2	10.8	5.2	19.1	6.0	19.0	9.9	6.0	4.1	7.2	10.9	61.2	6.1	......	13.0
Sept....	10.4	6.9	31.9	21.5	12.9	8.7	13.0	6.1	10.5	9.4	14.7	7.0	14.5	23.2	30.9	13.2	......	14 2
Oct.....	23.8	18.6	13.2	14.3	15.6	4.8	11.1	25.6	5.9	6.0	11.8	8.0	12.0	71.4	51.6	38.6	......	23.1
Nov....	46.5	32.6	42.2	41.6	13.2	19.6	16.6	31.4	19.3	11.3	93.3	25.0	23.8	65.9	53.3	174.7	......	39.5
Dec.....	110.7	22.3	264.4	89.0	19.0	11.0	34.9	24.4	9.6	31.9	76.8	36.6	29.6	100.6	127.3	33.5	......	52.5
Mean..	44.9	48.2	57.9	52.6	45.3	31.9	46.5	45.9	34.1	50.4	43.4	49.5	56.7	62.2	58.2	50.9	......	49.5

Above are quotients obtained from tabulated yield, for each month, for each year, and for each sixteen months of the same name, by dividing by the tabulated rainfall for the corresponding time.

TABLE No. 5.

Evaporation from Water Surface in Inches—Sixteen Years.

	1876.	1877.	1878.	1879.	1880.	1875–1890 and 1881–84	1885.	1886.	1887.	1888.	1889.	1875–90. Total.	1875–90. Mean.
January	*0.95	*0.95	*0.95	*0.95	*0.96	*0.95	*0.95	*0.95	*0.96	*0.96	*0.96	15.36	0.96
February	*1.05	*1.05	*1.05	*1.05	*1.05	*1.05	*1.06	*1.05	*1.06	*1.06	*1.05	15.80	1.05
March	*1.70	*1.70	*1.70	*1.70	*1.70	*1.70	*1.70	*1.70	*1.70	*1.70	*1.70	27.20	1.70
April	*2.98	*2.98	*2.98	*2.98	*2.98	*2.98	*2.98	3.12	3.07	2.78	2.84	47.57	2.97
May	*4.45	4.05	4.14	5.89	5.22	*4.45	3.77	4.45	4.83	3.36	4.67	71.42	4.46
June	6.44	5.68	6.26	6.32	6.46	*5.65	7.01	5.25	5 05	5.98	3.94	88.59	6.54
July	7.50	4.82	5.04	6.41	5.82	*6.98	7.09	5.59	5.96	5.67	6.04	95.72	5.98
August	6.21	4.40	4.33	5.23	5.34	*5.50	7.41	5.80	6.20	5.81	4.25	87.98	5.50
September	3.48	4.08	4.04	3.80	4.04	*4.20	6.13	4.55	4.57	3.91	3.08	65.88	4.12
October	3.12	2.51	3.52	2.99	2.79	*3.11	2.79	4.13	3.61	3.27	3.13	60.52	3.[illegible]6
November	0.66	*2.23	*2.23	*2.23	2.60	*2.23	*2.23	2.69	3.00	2.71	1.98	35.94	2.25
December	*1.51	*1.51	*1.51	*1.51	*1.51	*1.51	*1.51	*1.51	*1.51	*1.51	*1.51	24.16	1.51
Total	39.06	35.97	37.76	40.07	40.47	39.22	43.53	40.80	41.51	38.60	34.05	627.24	39.20

* From curve of mean evaporation, so adjusted as to vary very slightly from the means of observations. Unstarred numbers are from observations of Chestnut Hill Reservoir.

TABLE No. 6.

Yield of the Sudbury River Water-Shed in Millions of Gallons—Sixteen Years.

	*1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90. Total.	1875–90. Mean.
Jan.	248.0	1 550.3	1 686.9	4 362.1	1 698.2	2 716.0	966.9	2 892.2	780.6	2 319.9	2 878.5	3 405.3	6 036.0	2 454.9	6 486.0	2 924.0	43 305.70	2 706.61
Feb.	3 257.8	3 084.5	2 066.9	5 367.9	3 747.9	4 054.4	3 255.5	6 060.3	2 174.4	6 197.3	2 850.9	10 108.3	5 956.3	4 253.3	2 517.4	3 219.6	67 172.60	4 198.29
Mar..	3 867.2	10 691.1	11 604.1	8 454.4	6 651.4	3 332.2	9 333.6	6 617.5	3 765.0	8 824.3	3 565.6	4 798.8	6 685.4	7 547.6	3 120.2	8 492.0	106 440.70	6 652.54
Apr.	7 113.2	7 680.4	6 684.1	3 793.2	7 313.7	2 743.0	3 487.7	1 956.8	3 044.6	6 437.3	4 094.8	4 392.5	5 909.9	5 967.5	3 180.8	4 229.1	76 928.50	4 808.03
May.	2 863.1	2 744.0	3 354.2	3 361.6	2 701.4	1 247.0	2 249.6	3 010.9	2 185.3	2 402.1	3 114.4	1 679.1	2 351.6	3 805.6	2 050.3	3 186.4	42 305.50	2 644.09
Jun.	2 029.1	617.6	1 393.0	1 179.8	970.2	411.7	3 017.8	1 193.3	676.9	939.0	960.7	458.2	932.5	960.8	1 473.6	1 280 8	18 384.80	1 149.05
Jul..	774.7	441.1	486.1	309.6	381.7	427.7	641.3	201.1	268.9	521.6	144.7	269.7	267.6	273.6	1 477.0	250.0	7 139.16	446.20
Aug..	954.0	976.9	291.9	1 146.3	968.3	288.2	345.2	128.9	183.1	598.5	560 2	219.4	499.4	884.6	3 338.1	306.9	11 679.89	729.99
Sep..	483.8	430.2	139.0	376.1	330.3	188.4	444.9	691.5	205.9	99.1	273.1	264.9	250.4	2 604.8	1 867.7	1 031.6	9 670.70	604.42
Oct..	1 657.6	663.0	1 522.4	1 244.3	171.5	246.6	432.6	697.7	433.2	193.8	782.6	339.7	443.2	4 659.8	2 867.5	5 296.6	21 451.70	1 310.73
Nov.	3 038.0	2 537.8	3 307.3	3 949.0	482.5	481.7	891.0	472.3	461.7	395.3	2 656.3	1 518.5	831.5	6 222.1	4 378.8	2 740.1	34 363.90	2 147.74
Dec.	1 407.3	1 093.1	3 108.9	7 658.8	1 121.8	424.8	1 806.9	733.6	451.1	2 156.0	2 736.7	2 377.3	1 499.7	7 092.9	5 223.7	2 321.6	41 214.10	2 676 88
Total	27 693.7	32 309.9	34 444.8	41 202.0	25 628 9	16 661.6	26 876.0	23 656.5	14 620.5	31 084.1	24 718.4	29 831.7	31 663.5	46 717.3	37 971.0	35 277.4	480 057.25	30 003.68

*Area of water-shed: 1875–78, 77.764 square miles; 1879–80, 78.238 square miles; 1881–90, 75.199 square miles.

TABLE No. 7.

Yield of the Sudbury River Water-Shed in Cubic Feet per Second—Sixteen Years.

	*1876.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1835.	1886.	1887.	1888.	1889.	1890.	1875–90.	
																	Sum.	Mean.
Jan....	12.38	77.38	79.20	217 72	84.76	135.56	48.26	144.35	38.96	115.79	143.67	169.96	301.26	122.53	323.72	145.94	2 161.41	135.09
Feb....	180.02	164.67	114.21	296.62	207.10	216.31	179.89	279.62	120.15	330.64	167.54	558.57	329.13	226.93	139.11	177.90	....	229 94
Mar....	193 01	533.60	679.17	421.96	282.06	166.31	465.85	330.30	187.41	440.43	182.95	239.61	333.67	376.70	156.73	423.84	5 312.52	332 03
April...	366.86	396.11	288.00	195.63	377.20	141.47	179.88	100.92	157.02	332.00	211.19	226.54	304 80	307.77	164.05	218.11	3 967 53	247.97
May....	142.90	136.95	167.41	167.78	134 83	62.24	112.28	160.28	109.07	119.89	155.44	83.80	117.37	189.93	102.33	168.99	2 111 49	131.97
June...	104.65	26.69	71.84	60.85	60.04	21.23	155.64	61.54	34.91	48.43	49.65	23.63	48.09	49.04	75.99	66.06	948.18	69.26
July ...	38.67	22.02	24.26	15.45	19.05	21.35	32.16	10.04	13.42	26.03	7.22	13.46	13.36	13.66	73.72	12.48	356.32	22.27
Aug....	47.61	48.76	14.67	67.21	47 83	14.38	17.23	6.43	9.14	29.87	27.96	10.95	24.93	44.15	166.61	16.32	582.96	36.43
Sept....	24.96	22.19	7 17	19.35	17.03	9.72	22.95	35 66	10.62	5.11	14.08	13.66	12.91	134.34	95.81	63.20	498.76	31.17
Oct.....	77.74	28.10	76.98	62.10	8 56	12 30	21.69	34.82	21 62	9.67	39.06	16.95	22.12	232 67	143.12	264.35	1 070.67	66.92
Nov....	156.68	130.89	170 57	203.67	24.88	24.84	45.95	24.36	23.81	20.39	137.00	78.32	42.88	320.90	225.83	141.32	1 772.29	110.77
Dec....	70.24	64.56	155.17	382.26	65.99	21.20	90.18	36.61	22.61	107.61	136.69	118.65	74.85	354.01	260.72	115.87	2 057.02	128.66
Mean...	116.97	136.69	146.01	174.65	108.22	70.01	113.93	100.28	61.98	131.41	104.78	126.46	134.22	197.49	160.96	149.54	......	127.10

* Area of Water-Shed: 1875–78, 77.764 square miles. 1879–80, 78.238 square miles. 1881–90, 76.199 square miles.

TABLE No. 8.

Yield of the Sudbury River Water-Shed in Millions of Gallons per Square Mile—Sixteen Years.

	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90. Total.	1875–90. Mean.
January......	3.189	19.936	20.407	56.098	21.705	34.714	12.857	38.461	10.379	30.850	38.278	45.284	80.267	32.645	86.251	38.883	570.204	35.638
February	41.894	39.565	26.680	69.028	47 904	51.823	43.294	67.292	28.915	82.412	37.911	134.421	79.210	66.562	33.477	42.813	883.201	65.200
March........	49.729	137.481	149.222	108.719	72.237	42.692	124.119	88.005	49.933	117.346	48.745	63.816	88.903	100.366	41.493	112.928	1 395.633	87.227
April.........	91.472	98.766	71.809	48.779	93.480	35.059	46.380	26.022	40.487	85.504	54.453	58.412	78.690	79.356	42.298	66.239	1 007.205	62.960
May.........	36.819	35.286	43.134	43.228	34.629	15.938	29.916	40.039	29.061	31.943	41.415	22.329	31.271	60.604	27.265	42.360	655.137	34.696
June.........	26.093	6.665	17.914	15.173	12.401	6.262	40.130	16.869	9.001	12.487	12.776	6.093	12.401	12.644	19.695	17.032	241.625	15.096
July..........	9.962	5.672	6.251	3.979	4.878	5.467	8.668	2.674	3.676	6.935	1.924	3.586	3.568	3.638	19.641	3.326	93.634	5.852
August.	12.268	12.662	3.754	14.741	12.247	3.684	4.590	1.714	2.435	7.959	7.450	2.917	6.641	11.763	44.390	4.081	153.196	9.575
September....	6.221	5.532	1.787	4.823	4.221	2.408	5.916	9.196	2.738	1.318	3.632	3.523	3.329	34.640	24.704	13.718	127.705	7.982
October......	20.029	7.240	19.572	16.002	2.191	3.150	6.762	9.278	5.761	2.677	10.406	4.617	5.893	61.958	38.132	70.433	282.901	17.681
November....	39.067	32.635	42.630	60.782	6.156	6.156	11.848	6.281	6.139	5.256	35.324	20.193	11.057	82.743	68.229	36.438	460.844	28.178
December....	18.097	14.057	39.979	98.481	14.339	5.429	24.028	9.765	5.999	28.671	36.393	31.613	19.943	94.321	69.465	30.871	641.441	33.840
Total......	354.840	415.487	442.939	529.833	326.298	211.682	357.398	314.585	194.424	413.358	328.706	396.703	421.063	621.249	504.940	469.121	6 302.626	393.914

TABLE No. 9.

Yield of the Sudbury River Water-Shed in Cubic Feet per Second per Square Mile—Sixteen Years.

	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90.	
																	Sum.	Mean.
Jan	0.159	0.996	1.019	2.800	1.083	1.733	0.642	1.920	0.518	1.540	1.910	2.260	4.006	1.629	4.305	1.941	28.469	1.779
Feb.....	2.316	2.116	1.469	3.814	2.647	2.765	2.392	3.718	1.598	4.397	2.095	7.428	4.377	3.011	1.860	2.366	......	3.023
Mar....	2.482	6.862	7.448	5.426	3.605	2.126	6.195	4.392	2.492	5.857	2.433	3.185	4.437	6.009	2.071	6.636	69.657	4.354
Apr	4.718	6.094	3.703	2.616	4.821	1.808	2.392	1.342	2.088	4.415	2.808	3.013	4.053	4.093	2.182	2.900	61.946	3.247
May....	1.838	1.761	2.153	2.158	1.723	0.796	1.493	1.998	1.450	1.694	2.067	1.114	1.561	2.526	1.361	2.114	27.707	1.732
June....	1.346	0.343	0.924	0.782	0.640	0.271	2.070	0.818	0.464	0.644	0.659	0.314	0.640	0.662	1.011	0.878	12.456	0.779
July....	0.497	0.283	0.312	0.199	0.243	0.273	0.428	0.133	0.178	0.346	0.096	0.179	0.178	0.182	0.980	0.166	4.673	0.292
Aug....	0.612	0.627	0.187	0.736	0.611	0.184	0.229	0.086	0.122	0 397	0.372	0.146	0.331	0.687	2.216	0.204	7 646	0.478
Sept....	0.321	0.285	0.092	0.249	0.218	0.124	0.306	0.474	0 141	0.068	0.187	0.182	0.172	1.786	1.274	0.708	6.686	0.412
Oct.....	1.000	0.361	0.977	0.799	0.109	0.157	0.287	0.463	0.288	0.129	0.519	0.225	0.294	3.093	1.903	3.515	14.120	0.882
Nov....	2.016	1.683	2.193	2.619	0.318	0.318	0.611	0.324	0.317	0.271	1.822	1.041	0.570	4.267	3.003	1.879	23.252	1.453
Dec	0.903	0.702	1.996	4.916	0.716	0.271	1.199	0.487	0.299	1.431	1.816	1 678	0.995	4.708	3.467	1.541	27.024	1.689
Mean...	1.604	1.756	1.878	2.246	1.383	0.895	1.616	1.334	0.824	1.747	1.393	1.682	1.785	2.626	2.140	1.989	......	1.669

TABLE No. 10.

Calculated Yield of the Sudbury River Water-Shed on the Basis of the Land and Water Surface of 1890–91, in Millions of Gallons per Square Mile—Sixteen Years.

Note.—Water Surface in 1890–91 was about $3\frac{1}{3}$ per cent., varying slightly in different months, land nearly 97 per cent.

	1875.	1876	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90.	
																	Total.	Mean.
Jan.	3.528	19.862	20.693	66.477	21.761	34.760	13.304	38.651	10 505	31.128	38.374	45.524	80.261	32.658	86.249	38.883	672.608	35.788
Feb.	41.812	39.895	26.096	69.277	47.877	51.818	43.395	67.268	29 013	82.455	37.940	134.291	79.181	66.557	33.473	42.813	883.161	65.198
Mar	49.515	136.912	148.718	107.868	72.159	42.534	123.949	87.766	49.795	117.154	48.637	63.691	88.898	100.361	41.491	112.928	1 392.376	87.023
Apr...	90.144	97.582	70.834	48.779	93.049	34.930	46.166	25.874	40.296	85.408	54.350	57.957	78.679	79.338	42.291	66.239	1 001.816	62 613
May	36.016	34.296	42.379	41.705	33.412	15.638	29.786	39.961	28.959	31.776	41.321	22.013	31.237	60.597	27.250	42.358	548.704	34.294
June	25.875	5.637	16.760	14.562	12.006	4.900	40.011	16.627	8.806	12.327	12.567	5.600	12.393	12.617	19.684	17 032	236.304	14.769
July...	9.172	6.019	5.660	3.098	4.389	5.478	8.319	2.419	3.328	6.792	1.623	3.271	3.652	3.626	19.642	3.325	89.713	5.607
Aug.	12.096	11.231	3.515	15.194	12.337	3.556	4.273	1.349	1.893	7.898	7.418	2.681	6.649	11.764	44.415	4.081	150.349	9.397
Sept.	6.944	5.732	0.840	4.071	3.966	2.175	5.746	9.600	2.367	1.168	3.464	3.295	3.381	34.597	24.702	13.718	124.766	7.797
Oct.	20.177	6.911	20.814	16.608	1.895	3.242	5.698	9.147	6.093	2.605	10.498	4.369	5.893	61.975	38.139	70,433	284.297	17.769
Nov.	39.159	33.480	42.825	51.278	6.181	6.004	11.981	6.143	6.005	6.271	35.402	20.267	11.041	82.741	58.234	36.438	462.440	28.277
Dec.	17.673	14.399	39.205	98.334	14.567	5.563	24.135	9.778	6.356	28.810	36.363	31.657	19.961	94.314	69.463	30.871	641.439	33.840
Total	351.110	411.966	438.339	527.151	323.689	210.698	356.763	313.583	193.416	412.692	327.937	394.606	421.026	621.145	504.933	469.119	6 277.963	392.373

TABLE No. 11.

Calculated Yield of One Square Mile of Land Surface in Millions of Gallons—Sixteen Years.

Note.—Deduced from observed yield of the Sudbury River Water-Shed by making allowance for the yield of the portions covered by water.

	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90.	
																	Total.	Mean.
January.........	2.762	20.029	20.045	55.511	21.589	34.391	10.970	36.966	9.746	29.707	37.435	43.827	80.491	31.860	86.586	39.290	561.305	35.082
February........	41.997	39.371	27.195	58.709	48.024	51.849	42.729	67.495	28.319	82.000	37.557	135.806	79.681	56.932	34.275	42.818	884.757	55.297
March...........	50.005	138.211	149.868	109.814	72.589	43.038	125.826	90.247	51.479	119.405	50.711	64.753	90.056	101.241	42.533	113.208	1 412.984	88.311
April............	93.149	100.250	73.039	48.777	95.252	36.078	48.379	27.484	42.398	87.533	55.874	60.532	80.604	82.334	43.425	58.413	1 033.631	64.595
May.............	37.824	35.530	44.080	45.113	37.217	18.252	31.405	40.988	30.138	33.490	42.946	23.675	34.571	51.474	29.199	43.382	580.284	36.268
June............	26.365	7.921	19 347	15.919	13.369	7.724	41.518	18.561	11.049	14.052	15.552	8.118	14.302	15.176	20.974	19.792	269.738	16.859
July	10.960	5.235	6.996	5.076	6.051	5.394	10.820	5.058	5.453	8.439	5.128	4.801	5.015	6.288	17 959	5.584	114.266	7.142
August..........	12.494	14.307	4.065	14.157	11.996	4.476	6.900	3.690	4.812	8.679	7.809	3.791	7.429	11.921	45.991	5.201	167.719	10.482
September.......	5.599	5.259	3.079	5.825	5.232	3.682	6.872	7.252	4.025	3.175	5.752	4.376	5.408	33.017	24.641	13.123	137.318	8.582
October	19.832	7.673	17.945	15.345	3.262	2.785	5 985	10.080	4.815	2.968	9.483	5.054	6.558	63.077	38.777	58.435	282.078	17.630
November	38.949	31.555	42.153	50.161	5.123	6 707	11.271	7.013	6.469	5.203	34 295	19.779	11.625	82.890	57.650	38.332	450.175	28.136
December	18.636	13.621	40.963	98.820	13.356	4.958	23.492	9.542	5.340	27.595	36.888	30.659	19.220	95.260	70.899	29.544	538.983	33.686
Total	359.572	419.972	448.776	533.328	334.050	219.335	355.158	324.486	204.044	422.247	339.430	405.170	434.960	631.459	512.909	477.222	5 433.138	402.071

TABLE No. 12.

Calculated Yield of one Square Mile of Land Surface in Cubic Feet per Second—Sixteen Years.

Note.—Deduced from observed yield of the Sudbury River Water-Shed by making allowance for the yield of the portions covered by water.

	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90.	
																	Sum.	Mean.
Jan....	0.138	1.000	1.000	2.776	1.078	1.716	0.548	1.846	0.486	1.483	1.868	2 187	4.017	1.590	4.322	1.961	28.015	1.751
Feb....	2.321	2.101	1.503	3.797	2.654	2.766	2.361	3.730	1 565	4.375	2.075	7.504	4.403	3.037	1.894	2.366	......	3.029
Mar....	2.496	6.898	7.480	5.481	3.623	2.148	6.280	4.504	2.569	5.960	2.531	3 232	4.495	5.053	2.123	5.650	70.523	4.408
Apr....	4.804	5.171	3.767	2.516	4.913	1.861	2.495	1.417	2.187	4.514	2.882	3.122	4.157	4.246	2.240	3.013	53.304	3.331
May....	1.888	1.823	2.200	2.252	1.858	0.911	1.567	2.046	1.504	1.672	2.143	1.182	1.725	2.569	1.457	2.165	28.962	1.810
June...	1.360	0.408	0.998	0.821	0.689	0.398	2.141	0.957	0.570	0.725	0.802	0.419	0.738	0.783	1.082	1.021	13.912	0.869
July....	0.547	0.261	0.349	0.253	0.302	0.269	0.540	0.253	0.272	0.421	0.256	0.240	0.250	0.314	0.896	0.279	5.703	0.356
Aug....	0.624	0.714	0.203	0.707	0.599	0.223	0.344	0.184	0.240	0.433	0.390	0.189	0.371	0.595	2.295	0.260	8.371	0.523
Sept....	0.340	0.271	0.159	0.300	0.270	0.190	0.354	0.374	0.208	0 164	0.297	0.226	0.279	1.703	1.271	0.677	7.082	0.443
Oct.....	0.990	0.383	0.896	0.766	0.163	0.139	0.299	0.503	0 240	0.148	0 473	0.252	0.327	3.148	1.935	3.416	14.079	0.880
Nov....	2.009	1.627	2.174	2.587	0.316	0.346	0.581	0.362	0.334	0.268	1.769	1.020	0.600	4.275	2.973	1.977	23.217	1.451
Dec....	0.930	0.680	2.044	4.932	0.667	0.247	1.172	0.481	0.267	1.377	1.841	1.530	0.959	4.754	3.539	1.480	26.901	1.681
Mean...	1.624	1.775	1.902	2.261	1.416	0.927	1.652	1.376	0 865	1.785	1.439	1.718	1.844	2.669	2.174	2.023	......	1.703

TABLE No. 13.

Calculated Yield of One Square Mile of Water Surface in Millions of Gallons.—Sixteen Years.

Note.—From comparison of observed monthly rainfall with observed or assumed monthly evaporation from a water surface.

	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875-90.	
																	Total.	Mean.
Jan	25.373	15.120	39.206	81.194	26.381	45.289	79.907	86.737	32.151	71.687	65.170	93.932	73.686	55.438	76.640	27.285	895.196	55.950
Feb......	36.495	54.917	—5.405	85.556	43.655	50.920	62.494	60.756	48.921	95.496	48.921	90.891	64.823	45.793	10.514	42.665	837.412	52.338
Mar......	35.453	99.580	115.690	51.945	59.783	28.067	70.036	16.492	1.390	52.484	—10.949	33.193	55.612	75.076	11.557	104.881	800.290	50.018
Apr......	4.345	21.160	7.907	48.834	30 169	2.172	—17.031	—20.090	—19.725	24.765	10 862	—15.654	20.768	—6.169	9.906	—5.822	96.487	6.030
May......	—15.467	—29.318	—6.048	—55.334	—74.920	—58.810	—16.319	10.705	—4 605	—17.031	—4.953	—25.286	—63.693	25.634	—28.240	13 208	—350.477	—21.905
June......	11.991	—69.088	—56.568	—23.913	—26.607	—75.111	—2 694	—67.634	—54.743	—36.582	—72.035	—65.779	—41.709	—69.870	—19.812	—61.173	—711.227	—44.452
July......	—41.883	28.397	—32.481	—53.335	—43.047	7.873	—63.085	—73.182	—57.350	—40.232	—98.461	—40.406	—38.233	—72.382	67.690	—61.173	—611.280	—38.205
Aug......	0.621	—78.031	—12.478	45.306	22.228	—23.148	—71.983	—66 613	—82.810	—14.772	—3.910	—29.644	—15.988	7.212	—1.303	—28.414	—353.727	—22.108
Sept......	—13.382	19.707	—65.292	—47.774	—33 402	—42.352	—27.511	78.917	—46.675	—58.132	—64.388	—28.588	—66.481	81.246	26 503	31.282	—246.222	—15.389
Oct... ...	30.239	—15.276	104.359	60.346	—37.903	16.510	—2.694	—18.004	43.273	—10.949	40.058	—16.554	—13.469	29.891	19.551	128.603	348.981	21.811
Nov......	45.185	88.701	62.094	83.314	7.855	—14.164	32.342	—18.821	—7.299	7.212	67.169	33.975	—5.735	78.465	74.989	—17 900	517.382	32.336
Dec.	—9.906	30.669	—11.122	84.409	49.251	22.905	42.543	13.660	35.453	63.606	21.028	60.217	41.188	67.616	28.327	66.039	611.783	38.236
Total....	108.964	182.628	139.862	360.648	23.443	—39.849	86.005	3.023	—111.919	137.652	—1.478	91.497	20.769	327.850	276.322	239.481	1 834.598	114.662

TABLE No. 14.

Calculated Yield on One Square Mile of Water Surface in Cubic Feet per Second—Sixteen Years.

Note.—From comparison of observed monthly rainfall with observed or assumed monthly evaporation from a water surface.

	1875.	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1875–90.	
																	Sum.	Mean.
Jan.....	1.266	0.755	1.957	4.052	1.317	2.260	3.988	4.329	1.606	3.678	3.263	4.688	3.678	2.767	3.825	1.362	44.680	2.792
Feb.....	2.017	2.930	0.299	4.728	2.412	2.717	3.453	3.357	2.703	5.095	2.703	6.022	3.582	2.443	0.681	2.358	......	2.857
Mar. ...	1.769	4.970	6.774	2.693	2.984	1.401	3.496	0 823	0.059	2.619	—0.546	1 657	2.776	3.747	0.577	6.236	39.943	2.496
Apr	0.224	1.091	0.408	2.519	1.556	0.112	—0.878	—1.036	—1.017	1.277	0.560	—0.802	1.071	—0.319	0.611	—0.300	4.976	0.311
May....	—0.772	—1.463	—0.302	—2.762	—3.739	—2.935	—0.814	0.534	—0.230	—0.850	—0.247	—1.262	—3.179	1.279	—1.409	0.695	—17.493	—1 093
June...	0.618	—3.047	—2.917	—1.233	—1.372	—3.874	—0.139	—3.483	—2.823	—1.887	—3.715	—3.392	—2.151	—3.088	—1.022	—3.155	—36.681	—2.293
July ...	—2.090	1.417	—1.621	—2.662	—2.149	0.393	—3.149	—3.653	—2.862	—2.008	—4.914	—2.017	—1.908	—3.613	3.378	—3.053	—30.509	—1.907
Aug....	0.026	—3.895	—0.623	2.261	1.109	—1.165	—3.593	—3.325	—4.133	—0.737	—0.195	—1.476	—0.798	0.360	—0.055	—1.418	—17.655	—1.103
Sept....	—0.690	1.016	—3.367	—2.454	—1.723	—2.184	—1.419	4.070	—2.402	—2.998	—3.321	—1.474	—2.913	4.190	1.367	1.613	—12.699	—0.794
Oct.....	1.509	—0.762	6.209	2.513	—1.892	0.824	—0.134	—0.899	2.160	—0.546	1.999	—0.776	—0.672	1.492	0.975	6.419	17.418	1.089
Nov....	2.330	4.575	3.202	4.297	0.405	—0.730	1.668	—0.971	—0.376	0.372	3.464	1.752	—0.295	4.047	3.868	—0.923	26.684	1.668
Dec	—0.494	1.830	—0.555	4.213	2.458	1.143	2.123	0.682	1.769	3.175	1.050	3.005	2.056	3.370	1.414	3.296	30.534	1.908
Mean...	0.462	0.772	0.593	1.486	0.099	—0.168	0.365	0.013	0.474	0.581	—0.006	0.388	0.088	1.386	1.171	1.015	......	0.486

TABLE No. 15.

Average Yield of Three Water-Sheds in Millions of Gallons per Square Mile.

Month.	Lake Cochituate.			Sudbury River.		Mystic Lake.	Cochituate and Sudbury.	Cochituate, Sudbury and Mystic.
	1863–1890, Inclusive.	1875–1890, Inclusive.	1878–1890, Inclusive.	1875–1890, Inclusive.	1878–1890, Inclusive.	1878–1890, Inclusive.	1875 to 1890, Inclusive.	1878 to 1890, Inclusive.
January	33.693	32.512	36.763	35.638	40.613	34.864	34.076	37.387
February	45.688	49.128	52.336	56.200	69.621	53.213	52.164	56.056
March	63.449	69.877	66.396	87.227	81.477	66.804	78.552	71.226
April	62.681	47.760	44.619	62.960	67.320	45.382	65.356	49.107
May	32.967	26.294	24.641	34.696	33.839	32.737	29.995	30.406
June	14.482	12.733	11.789	15.095	14.681	18.455	13.913	14.975
July	10.093	7.345	6.706	5.852	5.619	10.249	6.699	7.491
August	14.238	11.998	12.672	9.675	9.686	11.940	10.786	11.399
September	13.406	12.141	12.833	7.981	8.782	9.110	10.061	10.242
October	18.732	17.022	17.370	17.681	18.158	14.863	17.352	16.797
November	26.906	27.156	24.714	28.178	25.893	23.765	27.667	24.787
December	29.988	33.067	35.124	33.840	36.100	31.160	33.463	34.128
Total	355.323	346.033	346.983	393.914	391.489	351.632	369.973	363.001

DISCUSSION.

JAMES B. FRANCIS, Past President Am. Soc. C. E.—The recent great rains and floods in the West and the comparative drought in the East have led me to consider if this condition can be explained on any general principles. I suppose the rainfall depends on the evaporation caused by the heat of the sun, which I take to be uniform, and that the evaporation and rainfall, taking the earth as a whole, are constant quantities, although we find practically as to a particular locality very great inequality. We have had in the West enormous rains and floods; in the East at the same time the rainfall was extremely small. I account for it thus: The water evaporated must fall somewhere, but is irregularly distributed, depending on the currents of air; if there is an excess in some places there must be a corresponding deficiency in some other places.

A. FTELEY, M. Am. Soc. C. E.—The results shown in the paper just read have evidently been collected with great care, but it omits one point which is of importance in the computation of the amount of storage room necessary in connection with a given water-shed and a given daily consumption. I refer to the fact that the total amount drawn from reservoirs in a year of drought, when they are partly or wholly emptied, is greater than the apparent capacity of the basins. I have observed several cases where the excess was from 20 to 30 per cent. and more. In New York, last year, the storage reservoirs were entirely exhausted and the amount of water drawn from them, exclusive of the natural flow of the streams, exceeded by more than 30 per cent. the visible capacity.

This result is obviously due to the fact that the ground around the reservoirs fills up at the same time as their level rises, and that the amount of water thus stored in the ground gradually returns to the reservoir as its surface is lowered. The amount of water stored by these means necessarily varies with the nature of the ground, being practically *nil* for rocky surfaces, and increasing with the porosity of the materials of which it is formed.

CLEMENS HERSCHEL, M. Am. Soc. C. E.—The point just made by Mr. Fteley is one of the two that I wished to make about the paper under discussion. The Boston observations were, I believe, the first made on the yield of drainage areas, and, being the first, they have been worked up with more care and more accuracy than any others we have. I think, also, that we have had, until recently, only the observations made on the Boston and the New York water supply drainage areas to go from in this country. Now, in the course of time, the computations and tables that have been made, have gone into more and more refinements, which is, of course, conducive to an advance of

knowledge. But the moment we pretend to work from observations of this kind and achieve precise results, the more essential it is that absolutely no modifying causes be left out of the computation. It thus has come about that this matter of the yield of a reservoir, being more than its capacity when measured from a topographical map, has become one of material weight.

The two papers we have recently had on this subject, that of Mr. Stearns and of Mr. FitzGerald, are notable papers, but embodied in them is the underlying defect which Mr. Fteley and I have pointed out.

To illustrate, I will take the paper of Mr. Stearns, who computes that to yield from a drainage area the moderate quantity of 800 000 gallons per square mile, it is necessary to have something like two hundred and twenty-five days' visible supply in store. A storage capacity of that magnitude is, however, rarely found on any city water-works in the United States. A result of that sort immediately put me on my guard against the whole series of results found, and, examining into the matter, I judged that the reason such results were arrived at was simply that the point had not been considered, that the water as it rises, elevates with it the whole water table of the country surrounding the reservoir. So that the reservoir volume, as computed from a topographical map, does not represent the true storage volume; the true storage volume is this computed volume, together with what may be called the invisible storage, which latter is under ground. Where, in the one case, we might compute that we had got only one hundred and twenty days' supply, we would have in reality one hundred and sixty to one hundred and seventy days' supply in store.

The second point I alluded to is in the way of questioning whether to accept the results founded solely on the drainage areas of Boston and New York, as giving results applicable in any and all cases. They are composed in the main of hills, not of a mountainous character; lie near the sea-shore, with ample expanse of meadow and farm in the lower portions. Being accidentally of like character, the impression has grown up and has been allowed to prevail, that because these two give concordant results, no others need be expected. They give a yield of something like 50 or 51 or 49 per cent. of the total rainfall, varying very largely during the different years, and being even unlike during years of the same rainfall; for, as we know, the distribution of rainfall during the year is of the utmost importance. To compute the yield of any stream from such records, and from the rainfall of the section of country in which that stream is situated, thus becomes an uncertain matter. The thing we are all after is knowledge of the flow of a given stream in cubic feet per second; of what our western friends call "the run-off," and I imagine, that if the measurement of cubic feet per

second had been as simple a matter as measuring rainfall, we should now have a much greater knowledge on the subject than we actually have.

I hope, as time goes on, cubic feet per second will be measured more and more, and it will follow that inches of rainfall will lose the importance that is now given them.

To illustrate in figures what I have just stated, I will read some statistics which I have gathered :

[From the "Annales des Ponts et Chaussées."]

JANUARY, 1892.

	Per Cent.
Durance, above Mirabeau, seven years' record........	74
" " Avignon, " "	67
Three tributaries of La Loire........................	71
Granit de Morvan....................................	71
Reservoir Gondrexange	53
Portion of La Seine..........	53
Reservoir Freyberg	45

While, as is well known, the general result on the Boston and New York drainage areas is not quite 50 per cent.

June 1st, 1891, to June 1st, 1892, was a very dry year in the vicinity of New York. The Croton water-shed yielded in that twelve months 15.74 inches of water; the yield of the Sudbury was, during the same time, 15.63 inches; the minimum on record on the Croton, 1880, being 15.33 inches.

During the same twelve months, the Pequannock water-shed, above the intake dam, near Charlottsburgh, situated in the same range of rainfall and of drought, but consisting largely of mountain slopes, yielded 23.23 inches of water, being nearly 50 per cent. more than the rate of yield from the Croton or the Sudbury water-shed.

I will say in this connection that it would be more scientific to divide rainfall and yields of streams into periods from June 1st to June 1st, than to divide the year in the usual way, from January 1st to January 1st, to get true annual yields.

FREDERIC P. STEARNS, M. Am. Soc. C. E.—As a part of my regular work, I have occasion very frequently to estimate the capacity of proposed sources of water supply. In making such estimates, I have always found the accurate records of the flow of streams, rainfall and evaporation, made in connection with the Boston Water Works, and for the most part under the supervision of Mr. FitzGerald, of the greatest value. I wish to emphasize one point that has already been brought out by Mr. FitzGerald, viz., the fact that these records include a most remarkable period of drought, and that estimates based upon them are consequently much more conservative than if based upon any other records with which I am acquainted.

I may say in the beginning, that I consider the records of the Sudbury River of greater value than those of the other water-sheds of the Boston Water Works, because there is practically no loss from this water-shed by the filtration of water through the ground to lower levels, and there is less complication due to public water supplies upon the water-shed, diversion of sewage past the lower dam, or by superficial and underground storage of which no account is taken.

Mr. FitzGerald calls attention in his paper to the fact that the Sudbury River records include two years, 1880 and 1883, of most remarkable drought, drier than any other in this vicinity for the sixty years from 1830 to 1890. The period of five years from 1879 to 1883, not only includes these two years, but it also includes three other years, in each of which the flow was below the average. These facts seem to furnish ample justification for Mr. FitzGerald's statement, that "judging by the past, we may feel assured that we have done all that a reasonable care demands, if our works are proportioned to the maximum drought ocurring in so long a period as sixty years."

By making a comparison between the Sudbury and Croton records, we are also confirmed in the opinion that the Sudbury records include a period of most remarkable drought, as will be seen by the following table :

COMPARISON OF SUDBURY AND CROTON RECORDS DURING THE DRIEST PERIODS, VARYING IN LENGTH FROM THREE MONTHS TO SIXTEEN YEARS.*

PERIOD.	Average daily flow for given period in gallons per square mile.	
	Sudbury.	Croton.
3 months	95 000	226 000
8 months	181 000	302 400
1 year	497 000	619 500
5 years	769 000	926 300
16 years	1 079 000	1 057 000

It will be observed from this table that the average flow from the Sudbury River water-shed per square mile during the driest periods of five years or less was very much less than from the Croton, while the average flow of the whole sixteen years was practically the same. It is also true that, taking the whole period in each case, the amount of rainfall was almost exactly the same.

The Croton records would naturally be used in the vicinity of New

* The Sudbury records are based upon the sixteen years from 1875 to 1890 inclusive. The Croton records include the seventeen years from 1870 to 1886, and are taken from a table made by Mr. A. Fteley, Chief Engineer of the New York Aqueduct Commission, and published in the Journal of the New England Water Works Association, for March, 1892.

York in estimating the capacity of water-sheds; but the above comparison at once raises the question as to whether water-sheds in the vicinity of New York are not about as likely to have these severe droughts in the future as those in the eastern part of Massachusetts; in other words, was the great drought on the Sudbury water-shed due to its location, or was it one of those great variations from the average conditions which occur from time to time in all meteorological phenomena without being assignable to any known law? I am inclined to the latter view, and consequently believe that estimates of the yield of water sheds in the vicinity of New York, in order to be on the safe side, should be based upon the Sudbury rather than upon the Croton records.

The table presented by Mr. FitzGerald, on page 267, is one by which the yield of water-sheds can be computed with very little labor, and with as much accuracy as would result from a tedious calculation based upon the detailed tables appended to his paper.

A table* similar to his, and also based upon the Sudbury records, is given below. It differs from Mr. FitzGerald's table, however, in that his is based upon one square mile of water-shed, including various percentages of water surface, while mine is based upon a square mile of land surface with varying areas of water surface in addition.

Daily volume in gallons per square mile of land surface.	Storage required in Gallons per Square Mile of Land Surface to prevent a Deficiency in the Season of Greatest Drought when the Daily Consumption is as indicated in the First Column, with the following Percentages of Water Surfaces.				
	0 per cent.	3 per cent.	6 per cent.	10 per cent.	25 per cent.
100 000	556 000	3 000 000	8 800 000	....	....
150 000	3 400 000	7 100 000	13 400 000	....	....
200 000	9 400 000	11 700 000	18 000 000	....	....
250 000	19 000 000	22 200 000	25 400 000	....	....
300 000	29 800 000	33 000 000	36 100 000	....	....
400 000	52 000 000	54 400 000	57 500 000	....	....
500 000	76 500 000	77 300 000	80 300 000	....	....
600 000	102 000 000	104 600 000	107 100 000	112 800 000	....
700 000	144 400 000	153 000 000	161 600 000	170 700 000	215 900 000
800 000	202 300 000	210 900 000	219 500 000	228 600 000	273 800 000
900 000	346 200 000	349 200 000	352 200 000	353 900 000	381 600 000
1 000 000	514 600 000	516 700 000	519 700 000	523 600 000	532 200 000

The second columns of the two tables are directly comparable because they represent the case where the water surfaces are absent. It will be seen that there is some difference in the results, though perhaps not enough to be of practical importance. The other columns are not directly comparable, but the comparative results can be shown

* This table was originally published in the annual report of the Massachusetts State Board of Health for 1890, page 342, and was also published in the *Journal of the Association of Engineering Societies*, October, 1891, and in the *Journal of the New England Water Works Association*, March, 1892.

by the following example, in which it is assumed that the area of the water-shed, including water surfaces, is 94 square miles, the area of water surfaces 6 square miles, and the available storage capacity 9 600 000 000 gallons.

By FitzGerald's Table.

	Square miles.
Area of water-shed, including water surfaces.	94
Area of water surfaces......................	6
Area of land surfaces......................	88
Percentage of water surfaces to total water-shed	6.8
	Gallons.
Available storage.........................	9 600 000 000
Available storage per square mile of water-shed	102 000 000
Average yield per square mile of water-shed, from table.............................	565 000
Daily capacity of whole water-shed.........	53 100 000

By Stearns' Table.

	Square miles.
Area of water-shed, including water surfaces.	94
Area of water surfaces......................	6
Area of land surfaces......................	88
Per cent. of water surfaces to land surfaces..	6.8
	Gallons.
Available storage.........................	9 600 000 000
Available storage per square mile of land surface...............................	109 000 000
Average yield per square mile of land surface, from table.............................	602 000
Daily capacity of whole water-shed.........	53 000 000

It is sometimes convenient in making preliminary examinations to remember that ordinary water-sheds where there is no storage, or where the amount of storage which can be made available is very limited, as is usually the case with mountain streams, will not furnish more than 100 000 gallons per day per square mile, while a large pond, draining a small water-shed, may in some instances furnish as much as 900 000 gallons per day per square mile of land surface. With the amount of artificial storage which it is usually feasible to provide upon water-sheds, the yield is likely to range between 300 000 and 600 000 gallons per day per square mile of land surface.

L. J. LeConte, M. Am. Soc. C. E.—Annual rainfall at and near San Francisco is subject to great variation, and furthermore, there is great difference in rainfall, in the same year, between localities only a few miles apart.

For example, at San Francisco we have as follows:

		Inches.
Minimum fall	=	7.4
Maximum fall	=	49.3
Mean annual	=	23.0

At the reservoir sites only 25 miles distant, we have:

Minimum fall	=	20.0
Maximum fall	=	81.0
Mean annual	=	47.0

Generally speaking, the minimum year's rainfall equals one-third the average; the maximum is more than double the average, and more than six times the minimum. Two dry years have come in succession, having only one-half the average rainfall.

The flow of streams is correspondingly irregular. They flow from December to May, and are dry the rest of the year. During dry years there is no flow and sometimes no fresh supply enters the reservoirs for a period of six hundred days. Meanwhile evaporation from water surfaces equal 60 inches per year. Hence the practice in California, as to storage reservoir, is quite different from that in the Eastern States, where streams are running, more or less, the whole year.

Large reservoirs are a necessity with us and the aim is always to catch all the flow that the water-shed furnishes, nothing is allowed to go to waste, as a rule. Reservoirs are generally designed on the basis of 85 million cubic feet of storage capacity for each square mile of water-shed. This is four to five times as much as most cities have adopted.

The "catch" or amount collected each year is also subject to still greater variation, but as an average may be estimated at 30 per cent. of rainfall. During years of light rainfall, even up to 20 inches, the catch is practically nothing. Where the variation is so great, it is impossible to make a catchment table which would command confidence, but if we take a wide grasp of the whole subject, I think we are justified in assuming the following approximations:

Rainfall.	Catch.
10 inches.	0.5 inches.
20 "	2.0 "
30 "	9.0 "
40 "	18.0 "
50 "	30.0 "

Mr. Stearns' statement that it is impracticable to secure more than 600 000 gallons per day per square mile of water-shed, is a very important contribution to our list of useful facts. At San Francisco similar observations have been made, and the final conclusion arrived at is, that a reliable daily supply of 1 000 000 gallons will require from 4 to 4½ square miles of water-shed. This is a result of fourteen years' experience (1877 to 1891), the mean annual rainfall being about 47 inches. The above catchment table throws ample light upon the true cause of this difference.

E. Sherman Gould, M. Am. Soc. C. E.—An important feature of this paper is its bearing upon the capacity of spill-ways, or overflows of reservoirs. The author lays down as guiding data, that, in districts analogous to those treated of, 1 square mile of drainage area furnishes approximately 1.5 cubic feet per second yearly average, which volume may be increased a hundredfold, or up to 150 cubic feet per second, for twenty-four hours, by maximum freshets. This maximum flow is certainly very large, being 3.4 times greater than that of the Sudbury water-shed in February, 1886, mentioned by the author. It will be interesting to make some calculations, to see to what dimensions of spill-way these data lead us.

I have stated elsewhere that, in want of a better, the following formula gives fairly well the proper average length in feet of spill-ways in terms of the drainage area expressed in square miles :

$$L = 20 \sqrt{A}.$$

I will use this length in the following calculations, determining the vertical dimension H, by means of the well-known formula for discharge over weirs :

$$Q = 3.2 \times L \times \sqrt{H^3},$$

in which $Q =$ cubic feet per second, $L =$ length of weir in feet, and $H =$ height in feet from sill to surface of smooth water. The coefficient 3.2 is, of course, subject to variation; the above value is a near enough average for the present purpose.

If, now, we calculated the values of L and H by means of these formulas for a series of reservoirs impounding the flow from water-sheds respectively of 9, 25, 100 and 400 square miles, yielding 150 cubic feet per square mile per second, we shall have :

Area,	9 square miles,		$L = 60$,	$H = 3.63$
"	25 "	"	$L = 100$,	$H = 5.16$
"	100 "	"	$L = 200$,	$H = 8.19$
"	400 "	"	$L = 400$,	$H = 13.00$

These values of H represent the height of the cross-section of water going over the sill of the dam. The crest of the dam must be raised still higher, the additional height depending upon the nature of the

dam, and the probable height of the waves which may be produced behind it. It is evident that the above figures call for spill-ways of great capacity. It would be very interesting to know if the results obtained agree with the practice of our leading hydraulic engineers.

Some years ago I made calculations for the proper height of spill-way corresponding to a maximum flow of 40 000 000 gallons per square mile per twenty-four hours, or about 62 cubic feet per second, this being, as far as I could ascertain, about the maximum observed at the Croton dam. I found, using the previously given formula for length, that the proper height, in feet, was the cubic root of the number of square miles in the water-shed.

Using this rule for the same areas as those previously taken, we have:

Area,	9	square miles,	$L = 60$,	$H = 2.08$
"	25	" "	$L = 100$,	$H = 2.92$
"	100	" "	$L = 200$,	$H = 4.62$
"	400	" "	$L = 400$,	$H = 73.7$.

For a maximum discharge of 62 cubic feet per second per square mile, we should then have the two general formulas for length and depth of spill-way:

$$L = 20\sqrt{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$D = \sqrt[3]{A} + C \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

in which L = length in feet; D = total height in feet from sill to crest; A = drainage area in square miles, and C = a varying height from high water-mark to crest of dam depending upon circumstances already mentioned.

To adapt (2) to a flow of 150 cubic feet per second per square mile, it will suffice to multiply $\sqrt[3]{A}$ by 1.77.

Such general formulas cannot be taken as absolute guides, but may be useful in affording a rational foundation for more special study in particular cases, the vital question always being: what is the maximum flow per second which can possibly occur under the most unfavorable combination of circumstances? Now, any engineering problem considered in this light, *i. e.*, that of the most unfavorable conditions conceivable, naturally leads to a very expensive solution, and it is, therefore, probable that the tendency will always be in dam building, to restrict the dimensions of the overflow below what the more pessimistic view of the case would dictate. In masonry dams built across rocky ravines, we are comparatively indifferent to the possibility of the dam being overtopped by a freshet, but in earthen dams this constitutes, perhaps, the greatest peril with which they are menaced. It is for this reasou, among others, that my opinion remains unshaken that such dams should always be provided with a substantial

center wall of hydraulic masonry, carried well above the sill or lip of the dam, and the rip-rapping of the inner slope carried still higher. As a rule we may expect that the heavier the freshet, the shorter its duration; so that if a dam thus protected should be overtopped, we might expect the flood to subside before it should have entirely stripped the outer slope, and thus caused the center wall to yield, particularly if liberal discharge culvert capacity is also provided and made use of. And even if the worst should occur, and the center-wall be breached, time, that priceless element in such cases, would be gained, and the catastrophe greatly modified. For the only difference between the harmless emptying of a reservoir, and a Johnstown disaster, is one of time.

As our profession, like that of the law, depends in its exercise largely upon precedent, it is greatly to be desired that statistics be gathered respecting the dimensions of the overflow of existing reservoirs, together with their corresponding water-sheds and meteorology.

If the proper depth of spill-way for discharge of 62 cubic feet per square mile per second be $\sqrt[3]{A}$, the proper depth for any other quantity, Q, may be obtained by multiplying $\sqrt[3]{A}$ by the coefficient C, derived from the relation, $\frac{Q}{62} = \sqrt{C^3}$, which reduces, using round numbers, to

$$C = \frac{\sqrt[3]{Q^2}}{16}.$$

We would then have the two general approximate, or rather tentative, formulas for length and depth of spill-way to discharge a given number Q of cubic feet per square mile per second, replacing those before given:

$$(1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots L = 20\sqrt{A} \text{ (as before given.)}$$

$$(2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots D = \frac{\sqrt{Q^2}}{16} \times \sqrt[3]{A} + C.$$

Mansfield Merriman, M. Am. Soc. C. E.—The reason why a rain-gauge on the top of a building indicates a less amount of rainfall than one on the surface of the ground, has not yet been made clear. It is generally assumed that the lower gauge gives the correct result, and that the indications of higher gauges are unreliable. Mr. FitzGerald asserts that the signal service observations of rainfall, made on the tops of high buildings, are untrustworthy. My own view of this matter is that the higher gauge gives the more reliable result, particularly in cities. This opinion is not founded on any experimental evidence, and therefore cannot be regarded as of much value; but as I have not seen the theory stated by any writer, it may be worth while to note it here and to give the reasons in favor of it.

The size of a rain-drop, it seems to me, is not constant, but increases

as it descends. This is due to the evaporation which constantly goes on, even during a rain and which is a maximum near the surface of the ground where the drops of rain are broken up by the impact on trees, grass and earth. Consequently, the air near the surface of the ground becomes saturated with moisture, and this is partly taken up by other drops, whose size accordingly increases as they fall. A rain-gauge on the surface of the ground hence measures too great a quantity, for a part of the water which falls into it has fallen before on surrounding objects.

If there is anything in this theory it would be expected that the difference in the readings of two gauges, one low and the other high, would vary with the humidity of the air and also with the force of the wind. A series of records with several self-registering rain-gauges will enable a discussion to be made which will throw some light on a question now in much doubt.

In a large city I can conceive of no better place for a rain-gauge than on the top of a building. No one would advocate putting it in an alley or court yard, and a public square filled with trees does not seem a good place. By locating it on the roof of a building the influence of heated pavements and walls is largely eliminated, and these would probably have more effect on the evaporation of water that has fallen than would be the case in a small town or in the country. Out on the treeless prairie it seems probable that the height of a rain-gauge is of less importance than elsewhere.

The only definite reason why a rain-gauge should be located at the surface of the ground, which I have been able to find, is that at a higher elevation the drops of rain "move in parabolic curves" whenever there is wind. This reason, however, explains nothing, for, whether the path of the drops be vertical, or inclined, or curved, if their size remain the same, the same quantity of water passes through two horizontal planes of different elevations. As numerous observations show that this is not the case, I conclude that the size of a rain-drop generally increase as it descends.

Edmund B. Weston, M. Am. Soc. C. E.—I have been very much interested in the reading of Mr. FitzGerald's paper, more especially as during the past twelve years, at different periods, I have spent considerable time in examining and comparing data relative to the flow of water from drainage areas. I do not know of any work of this nature that has been done more carefully than the work upon the Boston Water Works, and the manner in which the results have been presented by Mr. FitzGerald seems to be particularly valuable and instructive.

The following table, giving results from a number of European water-sheds, which I have compiled from some data that I have at hand, may be of interest for comparison:

TABLE SHOWING THE FLOW OF WATER FROM A NUMBER OF EUROPEAN WATER-SHEDS.

RIVERS, ETC.	Average annual rainfall in inches.	Mean discharge per square mile.	Per cent. of rainfall run off.	Drainage area in square miles.	Years in which observations were made.
River Lee, Hertfordshire, England....................	28.75	30.5	24	444.	1851, 1852, 1856
Loch Katrine, District Scotland	103.30	362.0	79	71.8	1854
Loch Lubnaig, District Scotland....................	66.70	225.7	76	69.7	1847
River Bann, and Lough Neagh, Ireland.............	25.92	94.8	78	2205.0	1856
Brosna, Ferbane, River, Ireland.....................	35.23	99.0	64	446.	1852, 1856
River Robe, Mayo, Ireland...	49.35	128.9	60	109.4	1851, 1852
River Saône, France..........	*32.6	86.1	61	11551.0	1852 to 1855, inclusive.

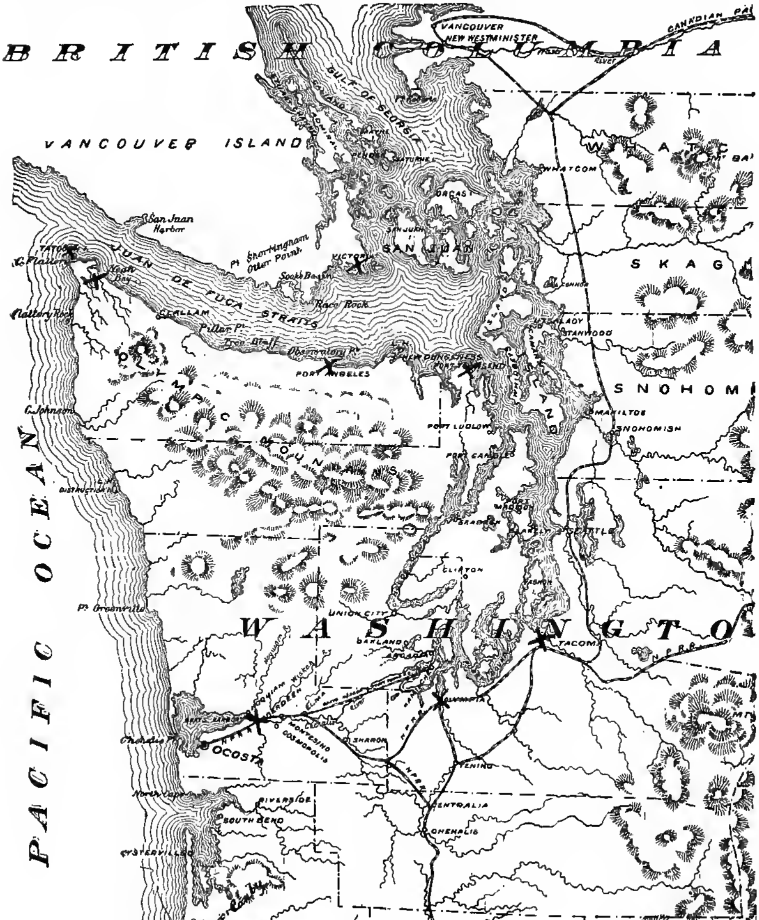
* Rainfall average of twelve stations.

I quite agree with Mr. FitzGerald in regard to the unreliability of some of the earlier records of rainfall. I can recall, among others, a series of observations covering nearly half a century, that were recorded by a man celebrated for his scientific attainments. These records, that were concluded in 1876 owing to his decease, have many times been used and quoted as examples of the early rainfalls. The gauge used for making the observations was located on the top of a fence about 6 feet above the ground, and the snow recorded as rainfall was simply the amount, melted, that was caught in the gauge. Experiments covering a number of years, that were made under my direction, show that at this elevation a gauge collects much less rain than one located about 1 foot above the ground, also that more or less of the snow that enters a gauge is not unfrequently blown out before it can be melted and measured. The results that I obtained indicate that in a gauge located 1 foot above the ground, and the snow measured at the surface of the ground (by cutting out and melting a section) the average annual rainfall will measure at least 13 per cent. more than in a gauge located and used as was the one which I have just mentioned.

B. W. DECOURCY, M. Am. Soc. C. E.—Mr. FitzGerald's interesting tables of rainfall induce me to write the following on the rainfall and phenomena arising therefrom in Washington and Victoria, B. C. I send some extracts from the records of the different stations kindly furnished me by the observers in this region. They will be found to

vary much in a small distance, only a few miles in position making a material change.

It is necessary to state that Mr. FitzGerald's remarks as to the accuracy of observations will obtain here much more than with the region he treats of, as many of the observers are volunteers, whom the



love of science has induced to devote some time from their other pursuits to this interesting subject. Still, the rainfall here is very great, and appears to be influenced by different causes.

Beginning on the foot hills of the Cascade Range of mountains,

there is a maximum fall, which decreases until those of the Olympic are reached; but thence there is an increase until the maximum is again reached at Neah Bay or the capes, at the entrance to the Straits of Juan de Fuca, and this maximum prevails along the coast and west of the Olympic Mountains.

This entire region is covered with a dense growth of timber, consisting of the Douglas fir, spruce, cedar and *tsuga-merteusiana* (commonly called hemlock, though quite a different timber from the hemlock of Canada and the east); besides, there is a dense growth underneath of sallal, vine maple and small woods, so completely impervious to wind and the solar rays, that there is scarcely any evaporation, and this, and the fallen timber hold back the rainfall from the streams and deliver it so gradually, that pronounced freshets are quite uncommon in the large or comparatively large streams.

There are no very large streams in this State west of the Cascade Range, and where freshets do occur, thay are caused by the melting snow. However, the entire region is cut up with small creeks, so that a 40-acre tract will be found watered with numerous small branches.

I have paid some attention to the rainfall in the valley of the Chehalis (one of our largest streams), which discharges into Gray's Harbor, and has a water-shed of about 3 000 square miles. The results show the smallness of the evaporation. When Chief Engineer of the State Harbor Line Survey of the different harbors forming the estuary of the Chehalis, called Gray's Harbor, I gauged the river and measured it accurately in several places.

Aberdeen, Hogmain and Ocosta show a rainfall of 90.82 inches, which is about that of the entire valley.

The rainfall is 4 689 767 064 934 gallons. At the river's mouth the average current is, when running out at low tide, 5 feet per second.

RAINFALL, 1891.

	NEAH BAY.	PORT ANGELES.	TACOMA.	ABERDEEN.	ABERDEEN, 1892.
January	15.93	2.96	5.38	......	6.75
February	6.64	.99	2.68	......	4.95
March	9.80	2.43	2.76	4.67	......
April	11.84	2.49	4.91	9.23	......
May	.91	1.53	1.92	2.75	......
June	6.17	.94	2.93	4.92	......
July	2.60	.00	0.05	1.21	......
August	2.11	1.58	2.76	2.02	......
September	10.78	2.35	4.17	8.62	......
October	10.06	3.33	5.15	6.69	......
November	23.06	3.20	7.63	19.96	......
December	23.91	6.78	10.55	19.34	......
	......	......	......	10.70	For 2 months, 1892.
	123.81	27.58	50.88	89.91	......

The sectional area is 26 400 square feet. The prevailing winds in winter are southwesters; in summer, those from the south and southwest bring rain, and northwest and north or easterly, clear and fine weather.

Neah Bay, average for eight years.......	104.
Port Angeles, average for eight years............	28.91
Tacoma, average for five years..................	42.84

	Average annual rainfall.
Dayton, Washington.............................	27.75
Fort Canby, Washington.........................	45.71
Olympia..	59.72
Tatoosh..	75.18
Port Townsend..................................	17.00
Portland, Oregon...............................	54.64

MONTHLY AND ANNUAL RAINFALL, VICTORIA, B. C.

In Inches. Ten Years—1881 to 1890.

	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	Mean.
January...........	3.84	2.28	5.67	6.25	9.15	3.09	6.68	5.02	2.84	3.64	4.72
February..........	8.84	3.55	3.26	2.11	3.84	3.17	4.82	1.77	1.12	2.33	3.48
March.............	1.57	4.02	1.56	0.38	0.32	2.94	6.36	3.53	1.60	1.50	2.27
April.............	2.70	1.24	2.02	1.02	0.53	1.67	0.76	2.26	1.83	0.86	1.49
May...............	1.48	0.53	0.74	0.73	1.30	0.45	1.32	0.19	1.01	0.98	0.87
June..............	1.57	0.42	0.53	1.59	0.25	1.00	0.48	2.23	0.77	2.10	1.09
July..............	0.90	1.24	0.05	0.48	0.06	0.80	0.27	0.34	0.00	0.64	0.48
August............	0.79	0.99	0.00	1.84	0.02	0 73	0.01	0.42	1.04	0.12	0.59
September.........	0.82	0.59	1.65	1.56	4.00	1.59	1.16	1.01	2.33	0.33	1.51
October...........	4.11	4.30	1.58	4.88	2.73	2.32	2.75	3.35	2.08	7 52	3.56
November..........	5.25	3.32	6.03	1.60	3.47	1.92	6.36	3.69	1.76	1.74	3.41
December..........	6.13	6.37	4.55	1.95	2.47	7.16	9.18	1.96	2.28	8.28	4.93
	37.99	27.85	27.65	23.49	28.14	26.84	38.06	25.77	18.66	29.94	28.41

I am under obligations for records to Mr. C. P. Culver, attorney at law, voluntary observer, at Tacoma; Mr. Irvine, at Port Angeles; Mr. Charles Addie, at Neah Bay; and Mr. Mack, at Aberdeen. Also to Mr. A. L. Going, C. E., at Victoria.

I am indebted to R. R. Ball, Captain and Assistant Surgeon U. S. A., for the record of rainfall at Port Townsend, Washington, as given below. Mr. Ball is Surgeon of the Post.

Monthly rainfall at Port Townsend, Washington, from July 1st, 1891, to June 30th, 1892.				Monthly average rainfall and melted snow for past ten years.	
1891.	Inches.	1892.	Inches.	Year.	Inches.
July....	.38	January.........	1.35	1882	2.02
August...............	2.52	February...	1.78	1883	1.68
September	1.78	March............	1.86	1884	1.63
October	1.12	April..............	2.42	1885	1.38
November...........	3.30	May................	2.90	1886	1.83
December...........	5.34	June....	.37	1887	1.56
				1888	2.03
				1889	1.25
25.12 inches total for year.				1890	1.66
				1891	2.08

Lewis M. Haupt, M. Am. Soc. C. E.—The subject that Mr. Francis has touched upon is one that is of national importance. I think this is a question which we should take a little time to consider in consequence of its humanitarian aspects. We want to do as much as we can to alleviate distress from floods.

I have recently prepared a paper on the subject of the Mississippi problem for the *Engineering Magazine*, expecting to bring the question up for discussion at another time; but as it seems to me to be germane here, with the consent of the Society, I will give a few abstracts from it.

"In the voluminous discussions and hearings upon this oft-mooted subject, no one has ever attempted to show that the amount of sediment ejected from the river's mouth at all approximates to that received from the tributaries or eroded from its banks and bed, yet it is a self-evident proposition that, unless these two quantities be equal, there must be an annual and permanent deposition in the bed of the stream, causing that bed, taken in toto, to rise. This opinion has been feelingly denied, and it is even attempted to prove that the beds of the far-famed Po, Danube, Yellow, Ganges and other alluvial streams of lesser extent are not rising.

"In a state of nature the river has provided its own 'dump' by overflowing the wide valley through which it flows, dropping its heaviest sediment nearest its edges, and building up a traverse highest near the brink, sloping away from the borders to the lower swamps and bayous beyond. Thus the rich alluvial territory from Cairo to the Gulf has been constructed out of the terrane from the mountains, and an ample dump has been furnished for the silt-bearing stream; but if the river be leveed along its entire course, and be compelled to bear its burden over these thousand miles, it will not be found able to cut deeper when surcharged with sediment, but it will drop its load in every available pool or bend at high water, and assuredly and rapidly raise its bed.

"The remedy suggested by a Southern author is to open up the lateral streams and divert some of the flood waters through more direct, shorter and steeper channels to the Gulf, the same as has been so frequently urged by Captain Cowden under the name of the 'outlet' system, and which has been so vigorously opposed by many engineers em-

ployed on the river, because of the alleged formation of bars below the outlets. This feature, however, is even now being carefully studied by some members of the corps of engineers in charge of sections of the river, and the data thus far collected would seem to show very grave doubts upon the supposed injury to the lower reaches from the outlets.

"Following Nature's method, however, and compromising with the land owner, it would seem practicable to provide a sufficient number of large lateral subsiding basins or lakes by enclosing extensive areas at intervals where the topography admitted of economical construction, into which the flood waters could escape, and in which, the velocity being reduced, a large part of the silt would be precipitated, while, after the passage of the crest of the flood-wave, the clearer waters from the reservoirs would return to the river and become useful for navigation. In short, instead of serving the sole purpose of maintaining the water supply for low stages, as do the reservoirs in the upper Mississippi, they would also reduce the rate of raising the bed by providing lateral dumping grounds outside of the bed of the stream, and would also reduce the flood plane and dangers from inundations. There are numerous places on the river where, by making return dikes extending back to the bluffs, many square miles of land, now of little value, might be utilized for such safety valves for the river, with substantial benefit and at a comparatively small cost.

"With reference to the probable effects of the lateral or outlet plan, while there is no grand precedent for it, there are many instances which would point strongly to its success, and one of the best which has recently fallen under my observation is to be found in the lowering of the flood plane of the Tyne, in England, due to the removal of bars and obstructions at its mouth and along its lower reaches as far as Newcastle.

"Captain Cowden has reduced his outlet theory to the aphorism 'make the overflow greater than the inflow and there can be no overflow.' In applying it he proposes to cut off a portion of the inflow by conducting it through lateral channels to the Gulf and thus preventing the tributary sediment from ever entering the main stream. This, certainly, is a desirable feature which appears to have been overlooked.

"It does not appear rational to expect any permanent improvement to a stream until the obstructions at its mouth be reduced and the surface slope in its lower reaches be increased, whether these obstructions be in the nature of mud or of water fed by tributary courses. The systematic improvement of the river must treat the problem as a whole, and provide at high stages for the rapid emptying of its basin at the outlet, the retardation of its filling by its tributaries, provision for deposition of its load and temporary escape of its excess of water along its course; while for the low water stages for navigation the stream must be canalized so far as practicable to retain a nearly uniform velocity."

B. M. Harrod, M. Am. Soc. C. E.—I want to say a few words, not in discussion of Mr. FitzGerald's interesting paper; but in reply to remarks relative to the Mississippi River, made part of that discussion by Professor Haupt. In these remarks, as I understand them, there was suggestion made of relief from great floods by the diversion of tributaries and by the use for storage reservoirs, of the great basins which lie on either side of the river.

The further diversion of any of the tributaries presents insuperable

difficulties. The Red River is already diverted from the Mississippi, about 6 miles from its mouth, into and through the Atchafalaya. The flood discharge of the Red River is about 200 000 cubic feet per second, while the Atchafalaya has a flood discharge, approximating twice that quantity. The latter stream therefore serves not only to divert the Red, but also, in emergency, as an outlet to the Mississippi. With this exception, the diversion of any one of the tributaries of the Mississippi River is impracticable.

To divert any other of them would involve a cut hundreds of feet deep, hundreds of feet wide, and hundreds of miles long, or an undertaking greater than the construction of the Suez Canal. An examination of the topography of the valley will establish this.

Regarding the use of the great alluvial basins as reservoirs for surplus flood water, there are difficulties of a different character. The lands in these basins are owned, under valid titles, by states, corporations and individuals. Many of them, which would be submerged in a reservoir, have much value, and are in successful cultivation. It is certainly true that all these lands are steadily appreciating. The Yazoo Basin is now substantially reclaimed from overflow, and the value of the lands therein has, in many cases, if not generally, increased 500 per cent., and homes and occupation have been given to a steadily increasing industrial population. The owners have in view, therefore, plans other than this abandonment as overflow reservoirs. They propose to complete their reclamation.

But I want more particularly to speak of the engineering objections to such a project. It is not established that general relief is found by using these basins as reservoirs to receive and hold back for a time, the water overflowing into them from great floods. An examination of the gauge record shows that, at the mouths of the tributaries draining these basins back into the Mississippi, the highest readings have been reached when a great overflow was returned to the main trunk, and that while the improvement or completion of a levee system has, for a first effect, the increase of flood heights along those parts of the fronts of the basin where overflow had previously occurred, yet that the transmission of the entire flood between levees has not had a corresponding effect in the gauge heights at the mouth of the tributaries. The use of the basins as reservoirs does not, therefore, serve as a general relief from excessive flood heights, and it certainly would not from overflow.

I think that the main idea underlying Professor Haupt's discussion is that the bed of the Mississippi River is rising. Observations bearing upon this point have been systematically made for the past thirteen years, and a few low water gauge records extend back about three times that period. It is, of course, impossible that this question of an elevation or depression of bed can be settled in so brief a time; but it is safe to say that, as far as these observations go, they

afford no evidence of any general or progressive rise of the bed of the river. They do indicate that below crevasses or outlets there is a loss of depth and section, and that the closing of these, by rebuilding the levees, tends to restore the previous capacity of the bed.

Other facts seem to connect the existing elevation of the bed of the river with the volume held within the banks. It has always been observed that the range between high and low water is different in different parts of the river. It is greatest at or about the mouth of a tributary when its natural discharge, together with the return of overflow into the basin, is added to the volume of the main river. It is less along the front of the basins, where the discharge is decreased by loss of volume over the banks. In general figures the flood discharge and the range from low to high water are both one-fourth greater at the mouths of the tributaries than they are at intermediate points along the front of the basin, or 43.5 and 35.3 respectively. In plotting the low and high water slopes, it is found that the high water line is quite regular when compared with that of low water, which has depressions where the flood volume is greatest and elevations where the flood volume is less. In other words, the irregularity of the low water line, which generally conforms to the shape of the bed, follows the depressions of the bed where there is greater, and the elevation of bed where there is the less flood discharge. This relation of elevation of bed to flood volume was among the earliest observations. There is no evidence that it is progressive. On the other hand, there is no evidence that the maintenance of a more nearly uniform flood discharge throughout the length of the river by levees has yet caused any greater uniformity of bed level, although it is reasonable to expect such a result.

Desmond FitzGerald, M. Am. Soc. C. E.—It is not entirely correct to say that no account has been taken in my tables of the storage in the ground, for the reason that more or less of this action has entered into the measurements of the Sudbury River in the past sixteen years, due to the drawing down of the reservoirs and Whitehall Pond during the summers. It was not from lack of some information on this subject, however, that I decided not to make a separate account of it in the tables. The soils surrounding reservoir sites differ so much in character and the situations of the reservoirs themselves affect this question to such a degree that it seems to me best, in the lack of adequate data, to leave any such allowance to the judgment of the engineer rather than to attempt to complicate an already complicated problem with such a variable and uncertain factor.

The following experiment was made under my direction to determine exactly what additional water was received from the storage in the ground in the case of Basin No. 4 of the Boston Water Works, situated on the Sudbury water-shed.

This reservoir of 162 acres has a surveyed water-shed of 6.434 square miles, including the reservoir. Its situation is high rather

than low, and the geographical formation is unmodified drift. Its water comes almost entirely from a feeder at one end of the basin and so is favorably situated for the experiment. A weir 20 feet wide was erected at the inlet, with a smaller weir for measuring summer flows, and a self-recording gauge registered continuously the amount of water entering the reservoir. The area of the water-shed above the river was 5.466 square miles, including the reservoir, which left only 0.968 square mile of contributing water-shed around the margins unmeasured. It was assumed that this area gave a *pro rata* supply. Rain and evaporation gauges were erected, the latter a floating gauge properly exposed. It will be impossible in the limits of this discussion to give the details of the experiment, which covered a period of six months, during which the reservoir was drawn down 12 feet. The following table, however, shows the results of the measurements and estimates:

Experiment to Determine the Yield of the Water Tables Surrounding Basin 4.

Date of Periods.	July 1-16.	July 16-Sept. 27.	Sept. 27-Oct. 7.	Oct. 7-Jan. 1.
Grades	214.81 to 214.84	214.84 to 202.91	202.91 to 202.93	202.93 to 207.85
Days	15	73	10	86
Flow over weir—gallons..	9 952 000	52 808 000	2 618 000	190 950 000
Flow from land below weir	1 287 000	7 062 000	366 000	26 515 000
Rainfall on water surface.	4 510 000	38 800 000	516 000	39 825 000
Water from water tables..	6 617 000	66 826 000	2 864 000	....
Drawn through gates.....	5 960 000	704 920 000	....	....
Leakage (measured)	1 886 000	7 696 000	817 000	7 866 000
Evaporation	12 870 000	43 350 000	4 687 000	22 365 000
Contributed to water tables........	....	....	....	3 099 000
Storage—gained or lost..	+1 650 000	—590 470 000	+860 000	+223 960 000

From this experiment it was assumed that if the water had been kept at a uniform level, there would have been a uniform subterranean flow into the basin of 300 000 gallons per day, derived from rain percolating through the ground; and with this allowance the water tables contributed to the storage capacity of the reservoir 44 900 000 gallons, while it was falling 12 feet. If these figures are correct, and no expense was spared to get at the truth, then the storage capacity of the reservoir to the 12-foot contour, viz., 590 470 000 gallons, received less than 8 per cent. additional supply from the water tables. It is obvious, however, that this figure would be very much larger in the case of a reservoir situated in low gravelly ground; and, on the other hand, less in a rock formation.

Admitting that there is a considerable accession to the storage from the water tables surrounding a reservoir, the question now arises, will it not be better, save perhaps in exceptional cases, to ignore this storage in order to be on the safe side.

The sixteen years during which the Sudbury has been measured contained a remarkably dry period, as I have already pointed out; and in this lies the great value of the results contained in the table and dia-

gram for storage capacity ; but is it not presumptuous to suppose that no greater period of drought will occur in the future? And is it not better to have the additional help of the water tables against such a contingency, rather than to cut down the capacity of the storage as outlined in the paper under discussion? Again, it is always wise to have some water left in the bottoms of our storage reservoirs for sanitary reasons.

Mr. Stearns has shown so well the agreement of our figures, although made on a different basis, that I will not dwell on this point.

Having found from topographical surveys and careful studies of the Sudbury River Water-Shed, that it will be possible to secure a total storage of 19 671 000 000 gallons on 75.199 square miles of water-shed, or 262 000 000 gallons storage per square mile, with 9 per cent. water surface, and providing in time of greatest drought a daily draft of 785 000 gallons per square mile, with a total daily draft of 59 000 000 gallons from the 75.199 square miles, and at a reasonable cost, I am led to believe that it will be found practicable and wise in some cases to develop a water-shed to this amount, but I cannot agree with Mr. Herschel, when he calls this a moderate development of a water-shed.

Professor Merriman will find in the literature on the subject, published in England, very full discussions and theories to account for the fact, which is undisputed in that country among experts, that the records of elevated gauges are untrustworthy. To satisfy myself in regard to the matter, I once had a series of towers built up to 60 feet in height, on which were placed rain gauges specially designed for the purpose of accurate observations, and which have been favorably mentioned in the reports of the Signal Bureau. There were nine gauges, from the surface upwards, placed so as not to interfere with each other, and daily observations were taken for three years, together with the velocity of the wind. The results convinced me that there was no doubt about the inaccuracy of the elevated gauges. The total rainfall collected at the height of 60 feet was about 82 per cent. of that collected at the ground level. It does not require these facts, however, to convince us of the accuracy of the statement made at the bottom of page 254 of my paper. It is only necessary to compare the observations made on the tops of high buildings with the observations made in gauges properly exposed on the ground in the same region, and which agree very well, even when several miles intervene, to become satisfied on this point. I believe the Signal Service officers will also endorse my statements. The wind is probably at the root of the trouble.

Mr. Gould's discussion in regard to spill-ways is interesting, but I suggest that, in the majority of situations in which water-works dams are situated, it is wrong to depend upon the core wall to save an earthen dam in times of freshet; and, after all, would it not be cheaper, considered merely as a matter of dollars and cents, to make the spill-way of ample capacity, rather than to shorten it, and repair the dam whenever it is overtopped?